

Textbook of **Soil Science**

R. K. Mehra



INDIAN COUNCIL OF AGRICULTURAL RESEARCH



Digitized by the Internet Archive
in 2018 with funding from
Public.Resource.Org

Textbook of Soil Science

Textbook of Soil Science

R.K. Mehra

Associate Professor

Department of Agriculture Chemistry and Soil Science
Maharana Pratap University of Agriculture & Technology
Rajasthan College of Agriculture
Udaipur



PUBLISHED BY
Directorate of Knowledge Management in Agriculture
Indian Council of Agricultural Research
Krishi Anusandhan Bhavan, Pusa, New Delhi 110 012

First Printed : June 2004
First Reprint : March 2006
Second Reprint : July 2011
Third Reprint : February 2013
Fourth Reprint : September 2014
Fifth Reprint : April 2016
Sixth Reprint : August 2017

Project Director (DKMA) : Dr S.K. Singh
Incharge (English Editorial Unit) : Dr Aruna T Kumar
Chief Production Officer : Dr V K Bharti
Assistant Chief Technical Officer : Kul Bhushan Gupta

All Rights Reserved
© 2017, Indian Council of Agricultural Research, New Delhi

ISBN : 81-7164-012-5

Price : ₹ 600

Published by Dr S.K. Singh, Project Director, Directorate of Knowledge Management in Agriculture, Indian Council of Agricultural Research, Krishi Anusandhan Bhavan-I, Pusa, New Delhi 110 012 and printed at M/s Chandu Press, 63, Patparganj Industrial Area, Delhi 110 092.

PREFACE

During my years as a teacher of soil science I have developed a methodology of presenting Soil Science to the students. Textbook of Soil Science is a translation of this methodology into a textbook.

Our understanding of the properties of soils, the process that occur in them and their behaviour under field conditions has advanced greatly in the past few years. It is my hope that the contents of this book will persuade some students to take the subject further. The textbook is primarily intended for the use of under graduate students of agriculture and is useful for some competitive examinations. The whole subject matter has been divided into 24 chapters and five sections which includes Soil Genesis and Soil Survey, Soil Physics, Physical Chemistry of Soils (Chemistry and Availability of major, secondary and micronutrients), Soil Biology and Soil and Environment. Questions at the end of each chapter will be useful in revision of the text of chapter for students.

I am grateful to the reviewers who made valuable suggestions for improvement and change. The authors and publishers of different books and literature consulted in the preparation of this text are duly acknowledged. I am thankful to my senior colleagues and friends for their encouragement during preparation of this manuscript. Special thanks are due to Dr. B.L. Baser Ex-professor and Head, Department of Soil Science, MPUAT, Udaipur and Dr. G.S. Sharma, Dean Rajasthan College of Agriculture, Udaipur. The author is extremely thankful to his mother, Smt. Satya Devi and wife, Anjna for their encouragement and inspiration during completion of this book.

The author gratefully acknowledges the Indian Council of Agricultural Research, New Delhi for the opportunity given and financial assistance to prepare this textbook. The author wishes to acknowledge the persons who have in some way contributed to the outcome of this book.

Despite all efforts, there remains chances of mistakes, omissions and scope for improvement for which suggestions are welcome.

R.K. Mehra

Contents

Section A : Soil Genesis and Soil Survey

Chapter	Page
1 Soil Development - The Earth	3
Earth's evolution, Earth's crust-Layer of the earth, Soil Defined, Components of soil	
2 Mineral composition of igneous sedimentary and metamorphic rocks	15
Minerals and their characteristics, Soil forming minerals, Rocks, Physical weathering, Chemical Weathering, Biological weathering, Classification of parent materials	
3 Weathering of Rocks and Minerals	36
Weathering a constructive and destructive process	
4 Soil Formation	46
Passive and active factors of soil formation, Parent material as a factor of soil formation, Relief or topography, Time as a factor of soil formation, Climate as a factor of soil formation, Biosphere as a factor of soil formation	
5 Soil Profile Development and Processes in Pedogenesis	56
Inherited and acquired soil characteristics, The soil profile, A pedon, Surface soil and sub soil, Master horizons: A theoretical soil profile, Soil morphology, Processes in pedogenesies, Fundamental versus specific soil forming processes, Fundamental soil forming processes and their characteristics, Specific soil forming processes and their characteristics	
6 Soil Classification	68
Early system of soil classification, Soil taxonomy, Advantages of soil taxonomy, Diagnostic horizons, Subsurface horizons, Higher and lower categories of the classification system, Higher categories of soil taxonomy: Order, Suborder and Great group, Suborder, Great group, Lower categories of soil taxonomy: Sub group, family and series, Nomenclature according to soil taxonomy, Soil mapping units, Important soil groups of India, Indian soils in US system of soil classification	
7 Soil Survey	96
Purpose of soil survey, Types of soil survey, Soil survey methods, Technologies for mapping, Uses of soil surveys	

8	Land Capability Classification	104
	Basis of classification, Capability classes, sub-classes and capability units	

Section B : Soil Physics

9	Soil Physical Properties	113
	Soil color, its significance and determination, Soil texture, Properties of soil separate, Determination of soil texture, Stoke's law, Importance of soil texture, Soil structure, Mechanisms of soil structure formation, Factors affecting formation of stable aggregates, Adhesion and cohesion, Adhesion and cohesion phenomenon, Flocculation and Deflocculation, Bulk density and particle density of soils, Factors affecting bulk density, Particle density, Soil porosity, Soil consistency	
10	Soil Water	139
	Structure of water, Water pressure in a capillary tube, Classification of soil water, Moisture retention in soil: Energy concept of soil water, Soil water potential, Soil moisture constants and their relationship, Measurement of soil water content, Movement of water in soils, Permeability, Infiltration	
11	Soil Air	163
	Composition of soil air and factors affecting it, Mechanism of gaseous exchange, Soil air in relation to plant growth	
12	Soil Temperature	171
	Factors influencing soil temperature, Thermal capacity (C), Thermal conductivity (K), Thermal deficiency (K / C), Soil temperature fluctuations, Effect of soil temperature on plant growth	

Section C : Physical Chemistry of Soils

13	Soil Colloids	183
	Properties of colloids, Characteristics of silicate clays, Physical properties of soil colloids, Clay minerals, their type and structure, Iron and aluminum oxides, Organic soil colloids, Groups responsible for ionic exchange	
14	Ion Exchange Phenomena	202
	Site of cation exchange, Cation exchange capacity, Factors affecting cation exchange capacity, Base saturation, Exchangeable cations and plant nutrition, Practical implications of cation exchange, Anion exchange	
15	Soil Reaction	220
	pH and its method of expression, Factors affecting soil reaction, Method of determination of soil pH, Soil pH and nutrient availability, Soil organisms and pH, Buffering, Buffering in soils, Buffering capacity of soils and buffering curves, Factors affecting buffering capacity of soils, Importance of buffering	

16	Origin, Reclamation and Management of Saline Alkali Soils and Quality of Irrigation Water	232
	Characteristics of salt affected soils, Causes of formation of saline and alkali soils, Effect of salinity and alkalinity on the growth of crops, Management and reclamation of saline and alkali soils, Agronomic practices, Relative salt presence of certain plants, Harmful effects of poor quality irrigation water, Criteria of suitability of water for irrigation, Classification of irrigation water, Methods for improvement and management of poor quality irrigation water	
17	Acid Soils	268
	Chief characteristics of acid soils, Active and reserve acidity of soils, Causes of soil acidity, Effect of soil acidity on plants, Liming, Efficiency of liming material, Method and time of application of liming material, Lime requirement of acid soil, Effect of liming materials on soils	
18	Chemistry and Availability of Major Nutrients	282
	Nitrogen cycle, Fate of nitrogenous and phosphatic compounds, Reactions of nitrogen fertilizers, The phosphorus cycle, Phosphorus compounds in soils, pH and phosphate ions, Phosphorus fixing power of soils, The potassium cycle, Forms and availability of potassium in soil, Quality and intensity factors as related to the availability of phosphorus and potassium, Factors affecting availability of nitrogen, phosphorus and potassium in soil	
19	Chemistry and Availability of Secondary Nutrients	312
	Importance of sulphur, The sulphur cycle, Role of sulphur compounds in soils and plants, Sulphur oxidation and reduction, Role of calcium and magnesium compounds in soil and plant, Factors affecting availability of calcium and magnesium in soil	
20	Chemistry and Availability of Micronutrients	327
	Macro and micro-nutrient, Role of micro-nutrients, Chelated nutrients, Factors affecting availability of micro-nutrient cations and anions, Source and need for micro-nutrient balance, Micro-nutrient fertilizers and soil management	
21	Soil Organisms	371
	Classification of soil organisms, Different group of soil organisms, Methods of studying soil organisms and their activities, Factor affecting activities of soil organisms, Microbial interaction, Soil plant interaction - Rhizosphere plant pathogen phyllosphere microrrhiza, Management of rhizosphere, Microbes and soil fertility, Photochemical reactions, Microbial population in soil	
22	Soil Organic Matter	402
	Composition and sources, Determination of soil organic matter, Carbon cycle,	

Humus - biochemistry and theory of humus formation, Characterization of humus, Soil enzymes, Role of organic matter, Organic matter decomposition and nutrient mineralization, Soil organic matter of plant growth, Maintaining of soil organic matter, Factors affecting the availability of soil organic matter

23 Biofertilizers 428

Biofertilizers - meaning, Classification of biofertilizers, Isolation identification and evaluation of organisms used as bio fertilizers, Mechanism of beneficial effects through bio-fertilizers, Factors affecting efficiency of bio-fertilizers, Commercial production of bio-fertilizers.

24 Soil and Environmental Pollution 456

Pollution - recognition of problem, Sources of soil pollution, Pesticides their kinds and reaction in soil, Effect of pesticides on soil organisms, Toxic compounds-hazards of chemicals, Organic chemical contamination - their prevention, Water pollution-fertilizer contamination of water, soil salinity, Atmospheric pollution, Effect of agricultural practices on environment, Environmental degradation and its management, Measures for effective control of pollution

SECTION A

**Soil GENESIS
AND
Soil SURVEY**

1

Soil Development – The Earth

Soil is the upper layer of the earth in which plants grow. The soils support us all—plants, animals and people either directly or from other life that comes from the soil. From the time man began to think, the soil has been recognized as the mother of all – plants, animals and man. Soil locks within its embrace the beginning of all life, and receives, at last, their discarded forms. It is the imperishable storehouse of eternity. The thin layer of soil covering the earth's surface represents the difference between survival and extinction for most terrestrial life.

The soils are developing as a result of chemical, biological and physical actions and reactions within the earth's crust. Knowledge of rocks and earth's crust is essential in understanding (i) the origin of different soils and (ii) causes of variations in properties of different soils.

EARTH'S EVOLUTION

The four major layers that make up the earth – the crust, the mantle and the outer and inner core - vary considerably.

Earth's crust is about 1% of the total volume. Beneath the earth's crust is the mantle, which accounts for 82% of the earth's total volume and descends nearly

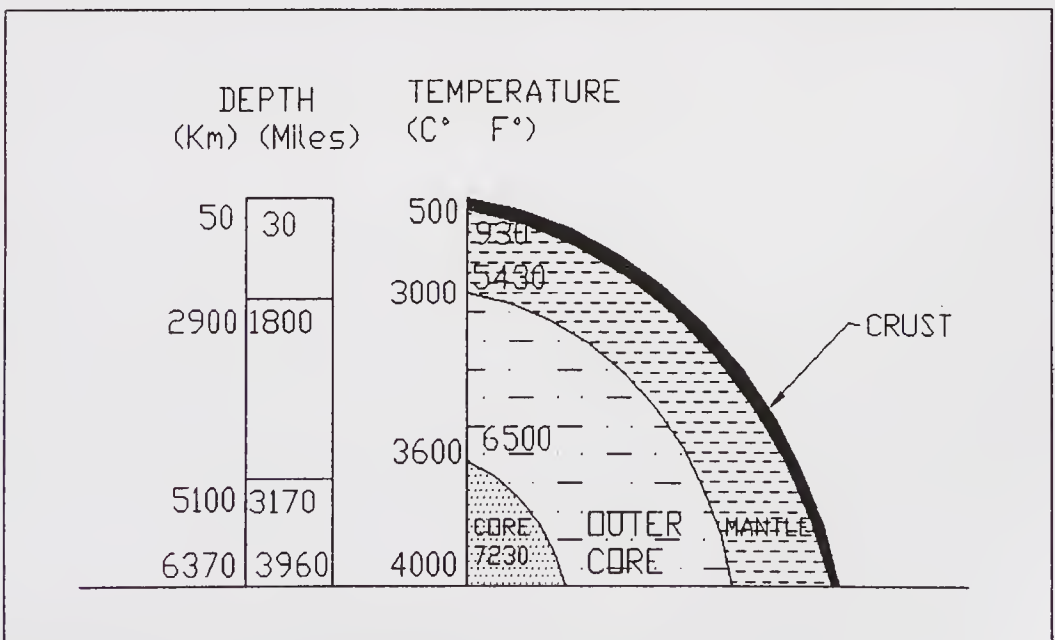


Fig. 1.1. A slice through the earth's center would show that it is built of four main layers.

3000 km (over 1800 miles) to the molten outer core. The central core is a ball of energy produced by radioactive elements. The temperature at the core is 4000°C (7230°F), which diminishes gradually to about 3000°C (5430°F) at the boundary between the outer core and the mantle. Heat was generated from the radioactive decay and cloud of gas. The gas cloud formed planetesimals, small bodies that smashed together generating enormous kinetic energy and subsequently heat. Thus, the earth and other planets in the solar system were formed.

EARTH'S CRUST – LAYER OF THE EARTH

The earth consists of a solid part (core, mantle and the crust) and the atmosphere surrounding it. Most of the earth's crust is covered with sea. The crust, made of rocks is about 80 Km thick. Earth's crust covered with water is

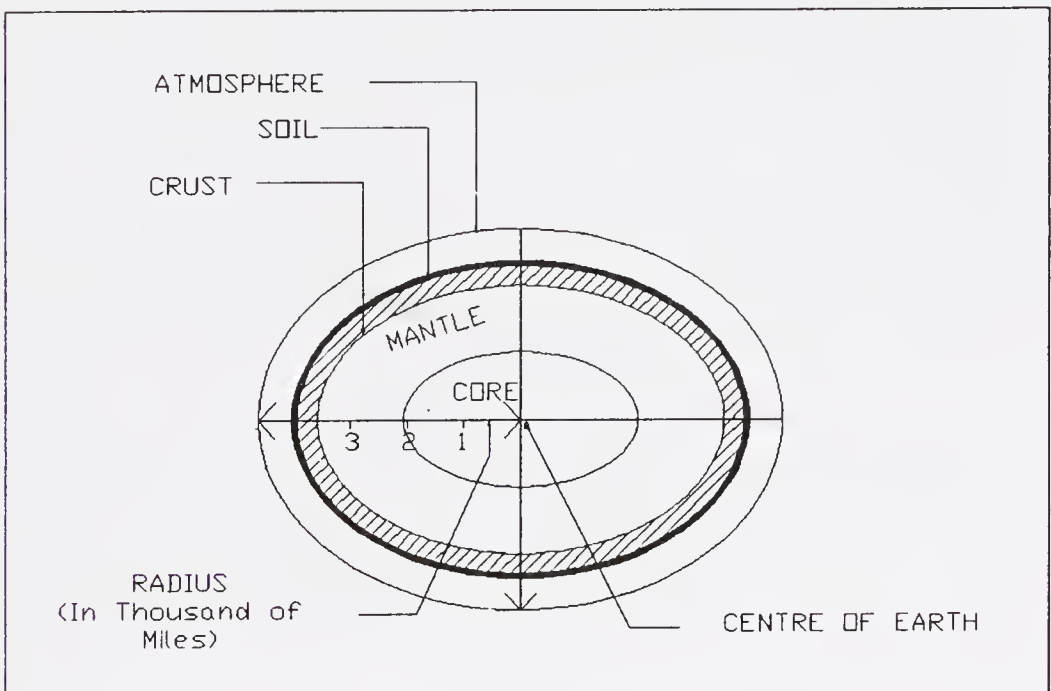


Fig. 1.2. Cross section of a slice of the earth showing soil as a thin layer between the atmosphere and the earth's crust.

called hydrosphere. Solid crust of the earth forms lithosphere. The atmosphere is about 272 Km deep. The soil forms a very thin layer between these two (Fig. 1.2).

The present form of earth has emerged after million of years in which liberation of gases from the molten masses, earthquakes, earth movements, volcanic eruptions have contributed. Though the outside of the earth is cool, the interior is still very hot. With depth, there is a tremendous increase in temperature. Because of the pressure from above, the interior of the earth remains in a solid state. The surface of the earth's crust is covered with mountains, depressions (covered with water) and atmosphere.

Spheres of the Earth

The earth consists of three spheres – the atmosphere, the hydrosphere and the lithosphere.

Atmosphere : All round our earth, there is a cover of air known as atmosphere. It extends to a height of 1600 Km from the earth’s surface, but has been under extensive studies only up to 300 Km . The atmosphere contributes 0.03% by weight of the earth. It is made up mainly of nitrogen (78%) and oxygen (21%). Argon, carbon dioxide, helium, ozone, neon, krypton are other gases which constitute only 1% of the total air quantity . Besides these gases, air contains water vapor and dust particles. At the sea level the atmosphere exerts a pressure of 1033.41gms/ cm²

Hydrosphere : The water cover found round the earth forms hydrosphere. About 71% of the earth’s surface is covered with water. The hydrosphere makes up only 6.91% of the earth mass, but by volume it is 15 times that of the visible land. Seawater contains highest amount of soluble salts. Average density of seawater is 1.026 due to mineral matter dissolved in it. The average content of mineral matter in the seawater is 3.5%.

Lithosphere: The solid crust of rocks on which we live is lithosphere. It accounts for 93.06% of the earth’s mass. Visible land is more concentrated in the Northern Hemisphere. Average chemical composition of the atmosphere, the hydrosphere and the lithosphere are as presented in Table 1.1

One hundred eight elements are known to occur in nature. But only few of these occur in abundance in earth’s crust. Oxygen and silicon exist to the extent of approximately 74%, aluminum, iron, calcium, sodium, magnesium, potassium

Table 1.1. Average chemical composition of the atmosphere, the hydrosphere and the lithosphere.

Atmosphere (0.3)		Hydrosphere (6.91%)		Lithosphere (earth’s crust) (93.06%)				Average of all sphere			
N	75.77	H ₂ O	96.24	O	46.46	H	0.14	O	49.02	C	0.18
O	22.69	Cl	2.07	Si	27.61	P	0.12	Si	26.67	Cl	0.19
H ₂ O	0.17	Na	1.14	Al	8.07	Mn	0.09	Al	7.50	P	0.11
CO ₂	0.04	Mg	0.14	Fe	5.06	C	0.09	Fe	4.71	S	0.06
Other	1.33	Ca	0.05	Ca	3.65	S	0.06	Ca	3.39	Ba	0.04
		K	0.04	Mg	2.07	Cl	0.05	Mg	1.93	Mn	0.09
		S	0.27	Na	2.75	Ba	0.04	Na	2.63	Sr	0.02
		B	0.008	K	2.58	F	0.03	K	2.40	N	0.03
		Cl	0.008	Ti	0.62	Sr	0.02	H	0.87	F	0.03
		I	0.00018	Rest	0.50	Ti	0.58	Rest	0.50		

* F.W. Clarke, Data of Geochemistry, US Geological Survey Bulletin 770, 5th edn. (1924).

make up nearly 24% and all others only nearly 1% of the earth's crust. Oxygen, carbon and nitrogen exist in a free state in nature. Most of the other elements are found in combination as minerals in rocks. The combination of these minerals forms silicates, oxides, carbonates, phosphates, and sulphates, which occur in the lithosphere. These elements when combine under suitable conditions give rise to a variety of minerals. Rocks when exposed to weathering agencies evolved into soils.

Origin of Soil

For many millions of years, the earth had no soil but only air, water, and rocks. Many geological processes were at work before the plants came. Mountains were thrust up and worn down by weathering and erosion. Changes from hot to cold and the formation of ice broke the rocks into small bits. Some parts dissolved and were carried deep into the rocks or to the ocean. Great streams and oceans washed the rock fragments, sorted them, and laid them down again. These were in turn pressed into mountains, and the process was repeated. Earthquakes, tidal waves, volcanic eruptions of ash and lava added complications.

The masses of ice plucked rocks from the hills they passed over, ground them into fine clay, sand and pebbles. Part of this mixture was left on the land from the melting ice, as glacial till. Glacial streams, sorted and left along their borders as terraces. Some of the fines were left as silts and clays in old glacial lakes. Even now the work of smaller glaciers can be seen in the high mountains or wherever there is much snow and cold.

Once the rocks were broken into fine particles, during periods of great dryness, the wind picked them up and carried them out over other land. From the deserts the fine material blew far away. The sand was deposited in dunes near the margins. The same kind of blowing on a reduced scale can be seen during extreme drought and where there is no protective cover of vegetation. Most of the soils, from relatively fresh volcanic ash are quite fertile.

Along with these processes of physical weathering go the slower chemical changes in the rock material. These chemical changes are slowest where it is cold and dry and fastest where it is hot and humid. In the tropics there are soil materials with chemical composition very different from those of the mother rock. Their iron and aluminium tend to accumulate and the other common mineral elements, even silicon, nearly disappear with time. These rock-destroying and earth-forming processes go on continually.

It takes a long time to produce an inch of soil that supports plants. Under favourable environmental and geological conditions the soil can evolve from the bedrock in 1000-1500 years. Soil is one of our most vital natural resources as it provides sustenance for plants, insect and animals.

In recent years, there has been an increased awareness of the multiple role, the soil has in the quality of life. Soils are not only the resource on which we grow our food, but are also the media in which we dispose of our wastes, develop recreational lands, support our environment and build our structure. Engineers, geologists and many others have interpreted the importance of Soil science information to natural resource management and environmental quality. The soil

scientists endeavour to improve our understanding of the earth's complex soil system in order to preserve and effectively utilize our soil resources.

Dr L.P. Wilding former President of the Soil Science Society of America stated that "Soil Science is at a critical stage" (*Geotimes*, February 1995). He emphasized the need to expand education for soil science students into areas such as waste recycling, soil and water quality, global climate change, soil stability, economic viability, and food security and safety. The time has come for developing programs that cross disciplinary boundaries, encompass ecological principles, quantify soil diversity and quality and enhance environmental protection. The international Congress of soil science in 1994, identified the following soil science agenda for the 21st century.

- Broaden soil science constituencies beyond traditional agricultural partners.
- Expand the focus of soil science to include food security, food safety ecosystem management, and sustainability of the biosphere, environmental protection, and the urban environment.
- Enhance the fundamental knowledge of soil systems by a more holistic, inter disciplinary approach that is dynamic and process oriented e.g. soils as the CO₂ sink in global climate change.
- Identify early warning systems of soil degradation so prevention may be substituted for remediation.
- Establish soil quality as a key indicator of environmental health linking food, land and people.
- Develop joint proposals, continuing education programs, and research methodologies among soil scientists from developed and developing countries.
- Make potential soil-science clientele aware of the products and expertise of the discipline.

Soil Development

Soils are composed of the unconsolidated organic and mineral materials on the earth's surface in which physical, chemical and biological differentiation into horizontal layers has taken place. Soil development includes (i) the breakdown of rocks to soil (ii) the changes in the soil profile brought about by natural processes of leaching, translocation of colloids, accumulation of organic materials and weathering. In other words, the changes that produce A and B-horizons are referred to as soil development. The decomposition of plant and animal residues represent a very essential series of reactions in soil development. The initial decomposition reactions are rapid, and they give inorganic salts, carbon dioxide and a highly carbonaceous residue, which is resistant to further decomposition. The rates of production and the rates of decomposition of these organic materials vary greatly with the environment under which a soil develops. Thus minute quantities of organic materials are deposited as in mineral soils. Also, conditions may be suitable for the production of larger quantities of organic materials but unfavorable for their decomposition. Under such condition soils consist of highly resistant organic materials. The translocation or movement of the products of weathering and of organic decomposition is one of the most important phases of

soil development. Soil is thus a dynamic system. Soil body becomes the habitat of plants, animals and micro-organisms. Dead tissues of these materials form organic materials. Thus a combination of mineral particles and organic materials form soil body. Living organisms in soil contribute to biological activity and support plant life by providing anchorage to roots, water and nutrient to support plant life.

SOIL DEFINED

The word soil comes from the Latin word *solum*, which means floor. 'A soil' means one individual soil body as 'A plant' means one individual plant. 'A soil' is a natural body – a piece of landscape – with depth, shape and area. 'The soil' is a collective term for all the soils of the world just as "the vegetation" is a collective term for all the plants. 'A soil' is a subdivision of 'the soil' having specific characteristics. The soil properties may differ with slope or type of parent material.

It is necessary to distinguish between soil and land. Land is a general term, which includes soil, organisms and minerals on it. Land with its vast resources of water, mineral and soil, is the foundation on which nations and civilizations are based. Land is a broader term, which includes the soil and also the physical attributes such as plant cover, water supply and location with respect to cities and means of transportation etc. For example forest land and grassland may include a variety of soils. The term soil is restricted to a collection of natural bodies with depth as well as breadth (three-dimensional). Soil is only a part of the land. A definition of soil, which very nearly meets its requirements, may be cited as under.

Soil is a natural body, dynamic and ever changing, formed by natural forces acting on natural materials. It is usually, differentiated into horizons of mineral and organic constituents of variable depth which differ from the parent material below in morphology, physical properties and constitutions, chemical properties and composition, and biological characteristics.

According to the Glossary of Soil Science Terms (Soil Science Society of America 1970).

- i) 'Soil is the unconsolidated mineral material on the immediate surface of the earth that serves as a natural medium for the growth of land plants'.
- ii) 'Soil is the unconsolidated mineral matter on the surface of the earth that has been subjected to and influenced by genetic and environmental factors of parent material, climate (including moisture and temperature effects), macro and micro-organisms and topography, all acting over a period of time and producing a product, that is soil, that differs from the material from which it is derived in many physical, chemical, biological and morphological properties and characteristics'.

A few of the other definitions given by scientists are:

"Soil is a natural body developed by natural forces acting on natural materials. It is usually differentiated into horizons from mineral and organic constituents of variable depth which differ from the parent material below in morphology, physical properties and constituents, chemical properties and composition and biological characteristics."

Joffe and Marbut

“Soil is the more or less loose and crumbly part of the outer earth crust in which by means of their roots, plants may or do find foothold and nourishment as well as all other conditions essential to their growth.”

Hilgard

Soil may be defined as “A dynamic natural body on the surface of the earth in which plants grow composed of mineral and organic materials and living forms.”

Buckman and Brady

“Soil is the uppermost weathered layer of the soil earth’s crust; it consists of rocks that have been reduced to small fragments and have been more or less changed chemically together with the remains of plants and animals that live on it and in it.”

Raman

The most recent definition of soil by Velayutham and Bhattacharya (2000) that seems most appropriate is as follows:

Soil is a dynamic natural body developed as a result of pedogenic processes through weathering of rocks, consisting of mineral and organic constituents, possessing definite chemical, physical, mineralogical and biological properties, having a variable depth over the surface of the earth, and providing a medium for plant growth.

Jenny pointed out that “all soils are anisotropic” that is the sequence of all soil properties differs profoundly along a line extending from the surface of the soil towards the center of the earth from that along lines parallel to the surface. This is justified in definitions given by different scientists. This anisotropy is basically the result of weathering of hard rocks and of reorganization, translocation and concentration of the mobile constituents due to the effects of the environment.

Characteristics of Soil

- Soil is a natural body, i.e. it is a natural medium for plant growth and cannot be synthesized artificially.
- Differentiated into horizons, the presence of different layers due to movement, translocation and accumulation of materials and
- Morphological, chemical and biological differences due to varying parent material and climatic conditions.

Functions of Soil

- Soil is an interface between the earth’s crust and the atmosphere. Thus it is involved in recycling of resources such as energy, water, gases and nutrient elements.
- Soil supplies mechanical support, water and nutrients to the growing plant and oxygen to the plant roots. The soil also stores the sun heat, and supplies it to the growing plant.
- Soil surface is used for production of agricultural crops. The soil is the habitat of a very large number of organisms of both plant and animal origin. Its non-agricultural uses include the construction of buildings, recreation and waste disposal.

New Approach Towards Soil

So far the knowledge of the chemical, physical and biological behavior of the soil was obtained mainly for obtaining higher yields. It is now realized that many problems must be studied without reference to yields. The increased use of fertilizers and pesticides has resulted in a steady rise of the chemical residues in soils. Recently, soil scientists have begun to realize the need for a compromise between maximum crop production and the conservation of a valuable natural resource and environment. The trend now is towards preserving the soils natural state by causing minimum disturbance when crops are grown which may be achieved by natural farming. Thus, great emphasis is being placed on the utilization of soils recognizing it as a natural resource. The fundamental knowledge of the soil as regard its origin and development, its nature and composition, its role in nutrition of animals and plants is very essential for better understanding.

Mineral and Organic Soil

A soil with no specific mention is understood to be a mineral soil. Inorganic constituents dominate in mineral soils. The majority of soils in India are mineral soils. In contrast to the mineral soil, organic soils develop from an accumulation of plant residues preserved by stagnant waters. Soils having more than 20% of organic constituents are arbitrarily called as organic soils. The agriculturist is primarily interested in organic soils, and the engineer in inorganic soils. The bulk of the soil material is mineral in character and has been derived from solid geological deposits. Organic soils are of two types i.e. peat and muck soils. These soils are classified on the basis of their organic matter content and stage of decomposition of the plant residues. Soils containing 20 to 50% of fairly well decomposed organic matter are called muck soils. These soils are only slightly decayed. Soils with more than 50% organic matter and markedly decomposed so that original plant materials cannot be identified are called peat soils. Organic soils must contain 33.3% organic matter in case such soils are not saturated with water.

The study of soil can be considered from the point of view of two aspects that is edaphology and pedology. Edaphology (derived from the Greek word edaphos, which means soil or ground and logos, which means knowledge) is the study of soil from the standpoint of higher plants including human use of land. Pedology (derived from the Greek word pedon, which means soil or earth) is the study of the origin, classification and description of the soil. Pedology does not focus on the soils immediate practical use. Thus, both the aspects are important for an understanding of soil development.

COMPONENTS OF SOIL

The soil consists of four major components: mineral matter, organic matter soil air and soil water. By volume, the air-dry soil contains about 45% mineral matter, 5% organic matter and 25% each of water and air. (Fig. 1.3).

The arrangement of solid particles and pore space is called the soil matrix. The matrix is a three-phase system of solid (mineral matter and organic matter) liquid (water) and gas (air). The proportion of air and water are subject to rapid

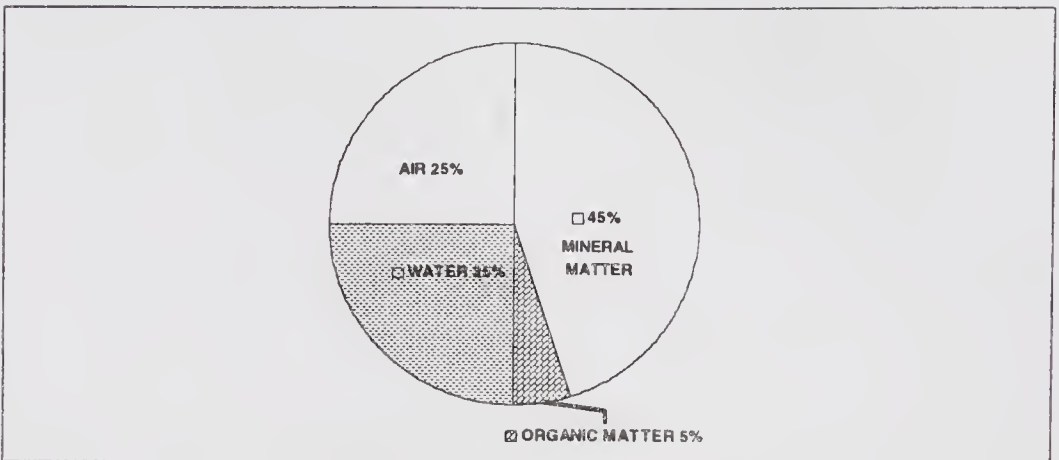


Fig. 1.3. Composition of Soil

and great fluctuations under natural conditions, depending on the weather and other factors. The interactions among these components are of great significance in providing plants with water, air, and essential nutrients.

Mineral Matter

Mineral matter is composed of small rock fragments and minerals of various kinds. In general, the primary minerals are present in coarser fraction (> 2 mm) of the soil whereas secondary minerals are dominant in the finer fraction (< 2 mm) of the soil.

Organic Matter

Organic matter consists of an accumulation of partially decayed and partially synthesized plant and animal residues. The important functions of organic matter in soil are follows:

Supply of plant nutrients: Organic matter is a storehouse of nutrients. These nutrients are released and made available to plants with the decomposition of organic matter. Decomposing organic matter is an important source of nitrogen, phosphorus and sulfur. Organic acids produced during the decomposition of organic matter helps in the release of plant nutrients from soil minerals.

Maintenance of soil structure: Organic matter helps to bind soil particles and provides aggregation suitable for maintenance of soil aeration.

Activity of soil organisms: Organic matter is the main source of energy for soil organisms. Micro-organisms derive their energy through organic matter; without which their activity would be adversely affected. Micro-organisms also control availability of plant nutrients.

Soil Water

It plays significant role in soil plant growth primarily in two ways:

- **Water held in soil pores:** It depends on (i) amount of water present (ii) size of the soil pores. The force of retention of water increased with the decreasing amount of water. Thus, if water is abundant, the forces of retention will be low and vice versa.
- **Soil water makes up the soil solution:** Water containing dissolved salts in it

is called soil solution. Soil solution is an important medium for supply of nutrients to plants. The nutrients may be supplied to plants through exchange phenomena between solid surface and soil solution and then between soil solution and plant roots. The supply of nutrients also depends on the concentration of H^+ and OH^- ions in soil solution as these ions influence solubility of nutrient elements.

Soil Air

Soil air occupies pores not filled with water. Hence, content of air is determined by water content of the soil. After a heavy rain the soil pores may be filled with water. After sometime when water moves downward, pores are filled with air. Thus relative amounts of air and water in the pore space fluctuate continuously. Soil air contains a higher concentration of carbon dioxide and small amount of oxygen than atmospheric air. This is due to respiration by soil organisms where large amounts of carbon dioxide is released into the soil and oxygen is consumed by organisms. Well-aggregated soil enhances root development.

Branches of Soil Science

Since there is an intimate plant and soil relationship, any discussion on soils would be incomplete without including these relationships. Therefore, to gain an understanding of soils, it is necessary to consider their development, classification, physical nature, chemical properties, biological activities, productive capacity and their tendency to erode. Thus soil science deals with soil as a natural body and a medium for crop growth. Different aspects of soil science may be studied under following major disciplines of soil science.

Soil genesis, Soil Survey and Soil Classification

Soil genesis: It deals with the mode of origin of the soil.

Soil survey: It is the study of morphological description, classification and mapping of soils.

Soil taxonomy: The grouping of soils based on their properties and characteristics. It is called soil taxonomy.

Soil Physics

The study of physical make up of soils, together with their resultant properties which affects the ability of soils to provide a medium for root development and supply of nutrients for plant growth. Important physical properties of soils are soil color, soil texture, soil structure and properties related to them.

Soil Chemistry

The study of chemical basis of soil formation and soil fertility is soil chemistry. It includes the role and function of individual elements and their compounds in the genesis of soils and their properties. Soil chemical properties regulate the availability of essential major and micronutrients, the activities of macro and micro-organisms in soil. Soil chemistry is also related to soil formation and pollution science in an important way.

Soil Microbiology

The branch of science dealing with micro-organisms and their activities in soil is known as soil microbiology. This includes bacteria, fungi, actinomycetes, algae and protozoa. These organisms through their varied activity contribute to the productivity of soils.

Soil Technology

It deals with the management of problem soils, i.e. saline, saline sodic, sodic and eroded soils.

Soil Fertility

The study of nutrient status of soil with respect to the amount and availability of nutrient to plants. Soil fertility is defined as the ability of soil to supply nutrients for plant growth. The concept of soil fertility includes how well the nutrients are protected from leaching and their enhanced availability to plants in addition to the quantity of nutrients the soil contains.

References and Suggested Readings

- Hilgard, F.W. (1906). *Soils, their Formation, Properties and Composition*. The Macmillan Company, New York.
- Joffe, J.S. (1949). *Pedology*. Pedology Publications, New Brunswick, New Jersey.
- Ramann, E. (1928). *The Evolution and Classification of Soils*. W. Heffer and Sons Ltd., London.
- Velayutham, M. and Bhattacharyya, T. (2000). Soil resource management. pp.3–4. *Natural Resource Management for Agricultural Production in India*, 14–18, Feb. 2000, New Delhi.
- Wilding, L.P. (1995). Quoted from *Geotimes*. Feb., 1995.

QUESTIONS

Q. 1. Fill in the blanks

- i) The four major layers that make up the earth are the crust, _____, _____ and _____.
- ii) The soil forms a thin layer between the _____ and _____.
- iii) In earth, with increase in depth there is a tremendous _____ in temperature.
- iv) About _____ percent of the earth's surface is covered with water
- v) Lithosphere accounts for _____ percent of the earth's mass
- vi) At the sea level atmosphere exerts a pressure of _____ gms. / cm^2 .
- vii) In general, primary minerals are present in coarser fraction of the soil whereas secondary minerals are dominant in the _____ fraction of the soil.

Answers

- (i) the mantle the outer core and the inner core (ii) atmosphere and crust (iii) increase (iv) 71 (v) 93.06 (vi) 1033.41 (vii) finer fraction

Q. 2. Choose the correct answer

- i) Pedology does not/ does focus on the soils immediate practical use.
ii) Soil air contains a higher/ lower concentration of carbon dioxide.

Answers

- (i) does not (ii) higher.

Q. 3. Define the following

- (i) Soil (ii) Edaphology (iii) Pedology (iv) Soil matrix.

Q4. Differentiate between

- (i) “A soil” and “The soil” (ii) Mineral soil and Organic soil (iii) Land and Soil

Q. 5. Write short notes on

- (i) Components of soil (ii) Soil development

Q. 6. Comment on the following statements

- i) All soils are anisotropic.
ii) Knowledge of rocks and earth is essential.

Q. 7. Answer the following in brief

- i) What are the important characteristics of soil.
ii) Enlist constituents of atmosphere.
iii) Enlist five major elements of the lithosphere.
iv) Define soil fertility. What is the concept of soil fertility?

Q. 8. Answer the following in detail

- i) Give a detailed account of lithosphere.
ii) Give a detailed account of the recent agenda for the 21st century in the field of soil science set by International Congress of Soil Science in 1994.

Q. 9. Give diagrammatic view of the following

- i) Slice of the earth showing its different layer.
ii) Composition of soil.



2

Mineral Composition of Igneous, Sedimentary and Metamorphic Rocks

Rocks are the chief sources for the parent materials from which soils are developed. The type of rocks and their mineral constituents influence the properties and characteristics of soils. Rocks differ from minerals in two ways. (1) Minerals possess a definite shape and chemical composition whereas rocks being a mixture of minerals may not have definite shape and chemical composition (2) Rocks may be formed as a result of combination of one or more minerals. For example, a mineral calcite may combine to form rock-limestone. On the other hand, rocks like granites, shale's or schist's are composed of several minerals. A study of rocks and minerals in relation to their composition and degree of susceptibility to weathering is an important aspect.

MINERALS AND THEIR CHARACTERISTICS

Minerals may be defined as naturally occurring inorganic, homogenous substance possessing definite composition, usually crystalline structure and characteristic physical properties. Minerals may be described by virtue of their essential characters like chemical composition, crystalline form, crystallophysical properties and specific gravity, which are identical properties or vary within certain limits in all the specimens of the same mineral properties. Non essential characters of minerals include colour, lustre, hardness, form and type of aggregate – depend largely on the presence of impurities or on the state of aggregation of crystalline individuals. Non essential characters are descriptive and have no exact definition. Essential characters can be expressed numerically and are perfectly definite. Important characteristics of minerals may be discussed with following characteristics:

Crystallographic Characters

Structure: Crystals can be formed (i) by solidification from a molten or liquid state (ii) by precipitation of matter from a solution (iii) by precipitation from vapour. The arrangement of the crystal forms is one of the most important characters of minerals. Some minerals have such a characteristic assemblage of crystal faces that they can be identified by crystal form alone, however, crystal of substances quite different chemically may appear almost identical e.g. silver iodide, zinc oxide and zinc sulfide. It has long been known that because of optical and other properties the regular forms presented by the exterior of crystals are the outward expression of an orderly internal arrangement of structure. Structure

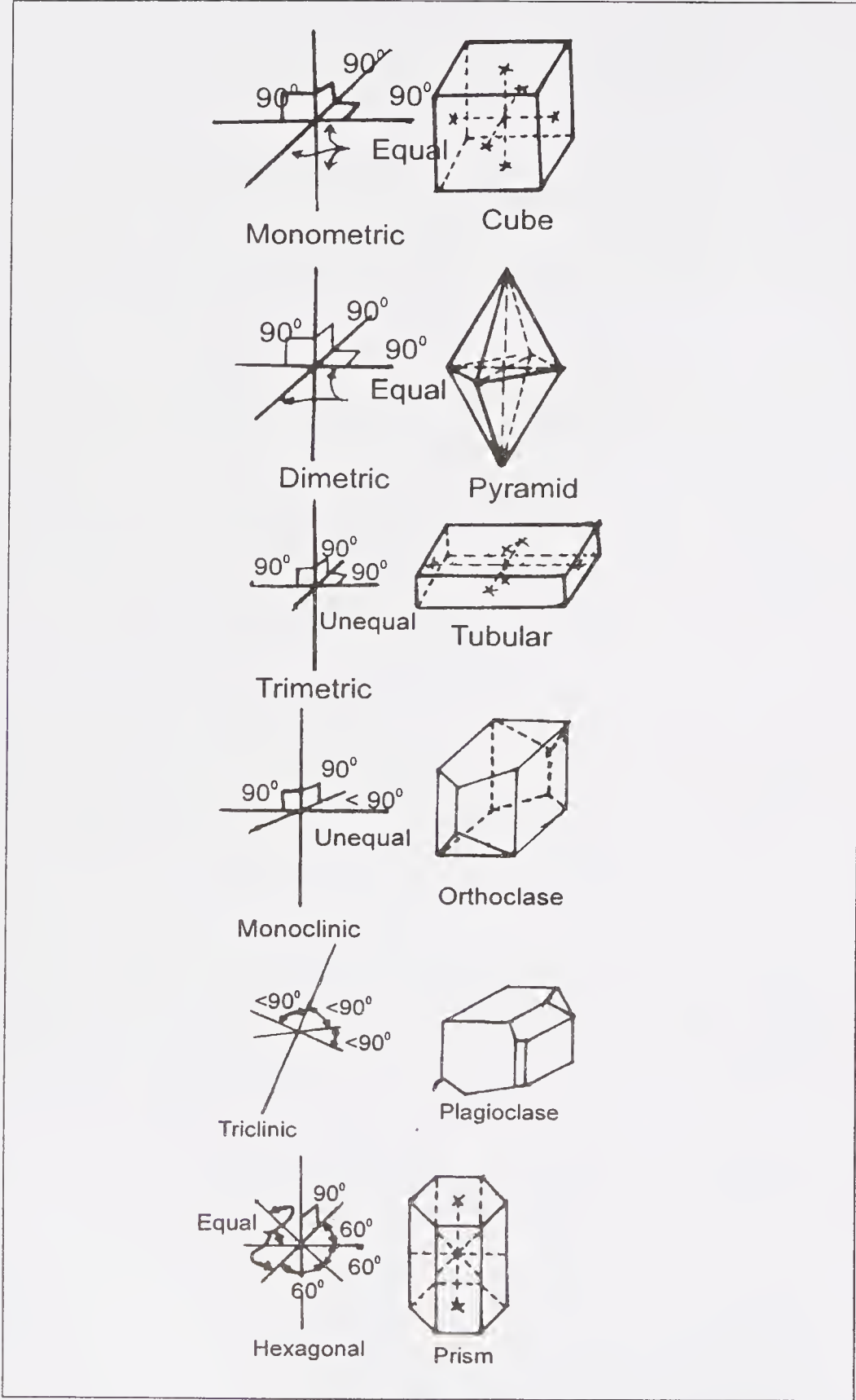


Fig. 2.1. Crystal forms and their shapes.

Table 2.1. Crystal forms and their characteristics

Type	Characteristics	
Monometric or Isometric	The three axes are of equal length and meet at right angles	Galena, halite
Dimetric or Tetragonal	Having three axes at right angles, two of which are of equal length and the third may be shorter or longer than the other two	Zircon
Trimetric or orthorhombic	There are three axes all at right angle but of different lengths	Sulphur, olivine
Monoclinic	There are three axes of unequal length, two of which are not at right angles while the third one makes a right angle with the plane of the other two.	Hornblende, orthoclase, gypsum, mica
Triclinic	There are three axes of unequal length but none forms a right angle with any other	Plagioclase
Hexagonal	This has three equal axes at 120° arranged in one plane and one more fourth axis of different length at right angle to the other three	Quartz, Calcite

deals with the distribution of faces and the angles between them on crystallized mineral specimens as presented in Table 2.1 and Fig. 2.1.

Transparency of minerals: *Opaque:* such as metals and most metallic sulfides. *Transparent:* Varieties of quartz. *Translucent:* Chalcedony (partial visibility).

Physical Characters

Colour: The colour of minerals first attracts attention. Colour of a mineral may be due to interference of rays of white light at the surface of thin crevices. It may also be affected by impurities in minerals. Thus, fluorspar and quartz when chemically pure crystals, are colourless and transparent but these minerals exist in every shade of colour. This is due to different colouring matter so small in amount that their exact nature is difficult to determine. Limonite is brown or yellow, magnetite is brownish black and hematite is red brown.

Streak: More constant than the colour of a mineral is the colour of its powder. This is obtained by scratching the mineral, or by crushing a fragment of it on a sheet of white paper. Ores of iron may generally be distinguished by their streak.

Lustre: Lustre of a mineral may be modified by the state of aggregation. The surface of a mineral reflects light in different ways. In general, minerals can be divided into two groups on the basis of lustre. Those with the lustre of a metal are metallic i.e. gold, copper, graphite, pyrite. Most others are non-metallic, i.e. diamond, resin, broken glass, quartz.

Magnetic, electrical and thermal characters: These properties are related to crystal form of minerals. Magnetite is the only mineral, which is strongly magnetic

with polarity. The pole of a strong electromagnet attracts many minerals. Most minerals with a metallic lustre are good conductors of heat and electricity; others are bad conductors. For example, graphite is a good conductor, while diamond is bad one.

The specific heat and melting point of minerals are essential characters capable of exact measurement and numerical expression, but they are not often used.

Characters Depending on Cohesion

Cleavage and fracture: Some minerals (e.g. a sheet of mica) are highly elastic, springing back to their original shape after being bent. Others (i.e. talc) may be readily bent but do not return to their original form when released, they are said to be pliable or flexible. The fractured surface produced when a mineral is broken is called the “fracture”. In many cases when a crystallized mineral is broken it separates in certain definite directions along plane surfaces. For example, calcite with its three directions of perfect cleavage parallels to its faces.

Hardness: Hardness, or the resistance, which a substance offers to being scratched, is an important character of minerals. It must, however, be remembered that the hardness of an incoherent or earthy aggregate of small crystals will be very different from that of a single crystal. A comparative scale of hardness was devised by Mohr in 1820 for the purpose of giving a numerical statement of hardness to minerals, as follows :

- | | | | | |
|---------------|-----------|------------|--------------|-------------|
| 1. Talc | 2. Gypsum | 3. Calcite | 4. Fluorspar | 5. Apatite |
| 6. Orthoclase | 7. Quartz | 8. Topaz | 9. Corundum | 10. Diamond |

A mineral, which is capable of scratching calcite and can itself be as easily scratched by fluorspar, is said to have hardness of $3\frac{1}{2}$. Talc and gypsum can be scratched readily with the fingernail.

Specific Gravity

The specific gravity or density of a mineral is a number expressing the ratio between its weight and the weight of an equal volume of water at 4°C . It is an essential character, which has the advantage of numerical expression. Minerals may be classified as light or heavy depending upon their specific gravity.

Type of mineral	Specific gravity	Examples
Light minerals	Less than 2.85	Feldspars (2.65), quartz (2.60) muscovite (2.5-2.75)
Heavy minerals	More than 2.85	Hematite (5.3), pyrite (5.0), Limonite (3.8), Augite (3.1-3.6), Olivine (3.50), Horn blende-amphiboles (2.9-3.8)

Radioactivity

The radioactivity of minerals containing uranium and thorium has been of interest to mineralogists. A simple and quick test for radioactivity can be made

with a Geiger Muller counter, which counts the number of α or β particles emitted by the radioactive mineral. The method helps in recognizing these valuable ore minerals and also gives a rough indication of their concentration. Determinations of the ratio of the amount of uranium to the amount of various products of its decay (radium, helium, lead etc.) present in various radioactive minerals give some idea of the period of time during which these products have been accumulating. In this way estimates have been made of the age in years of these radioactive minerals and even of the age of the earth.

Chemical Composition

It is estimated that the minerals of the earth's crust consist of about 47% by weight of oxygen, 27% of silicon and 8% of aluminium. Silicates and especially aluminium silicates therefore predominate. Based on their chemical composition, minerals may be classified as follows:

Oxides	: Limonite, Hematite, and Quartz
Carbonates	: Calcite, Dolomite
Silicates	: Orthoclase, Micas, Olivine, Plagioclase, Anorthite, Hornblende
Sulfates	: Gypsum
Phosphates	: Apatite
Halides	: Rock salt

Factors controlling relative stability of minerals

These factors include the relative ease with which a mineral can weather. There are differences in the ability of different minerals to weather. Thus the relative stability of minerals to weathering and to decomposition is related to following factors:

Radius of the Cation

Tetrahedral unit: Oxygen ions have a radius of 1.32 Å (primary building block of all aluminium silicates consists of silicon and oxygen). Thus a sphere with a radius of the size of silicon ion, radius 0.39 Å fits this interstice without any distortion. This forms stable structure. An Al^{+3} with a radius of 0.57 Å distorts the tetrahedron markedly. Thus, presence of Al^{3+} in the tetrahedral positions imparts aluminium silicate mineral instability. Also this instability increases with the number of such ions.

Octahedral unit: The radius of a sphere that would fit in an octahedral position is calculated to be 0.70 Å. Among the ions commonly found in this position, the Mg^{++} with a radius of 0.78 Å and Fe^{3+} with a radius of 0.67 Å appear to fit without distortion, but Al^{3+} with a radius of 0.57 Å and Fe^{2+} with a radius of 0.83 Å are either too small or too large. The structure with Mg^{2+} and Fe^{3+} are, therefore, more stable than structures with Al^{3+} and Fe^{2+} .

Linkages of Silica (tetrahedron) and Aluminium (octahedron)

These linkages have also been used as a basis for classification of aluminium silicates.

i) Independent tetrahedrons	- SiO_4	Decreasing Stability
ii) Double tetrahedrons	- Si_2O_7	
iii) Silicates with isolated and Double tetrahedrons	- $\text{SiO}_4 + \text{Si}_2\text{O}_7$	
iv) Silicates with chain structure	- Si_2O_6	
Single chain of tetrahedrons	- Si_2O_6	
Double chain of tetrahedrons	- Si_4O_{11}	
v) Infinite sheet of tetrahedrons		

Chemical Composition

Basicity of the mineral: The more basic mineral crystallizes first followed by minerals with a decreasing order of basicity. The order of crystallization is:

Olivine > Enstatite > Augite > Hornblende > Biotite > Quartz > Zeolite

The increasing basicity of the mineral is due to the decreasing degree of tetrahedral linkages.

Presence of ferrous ion: The presence of ferrous iron and other cations that oxidise during weathering reduce the structural stability. This is because in the process of oxidation there is exchange of cations to maintain electrostatic neutrality. Since such cation may be involved in the linkage of tetrahedrons, its departure would weaken the structure.

Size and Shape of the Ions

Volume: The smaller the volume occupied by a given number of O, the more stable is the mineral. The greater resistance of microcline, $\text{KNa}(\text{Si}_3\text{AlO}_8)$ as compared to orthoclase, $\text{KNa}(\text{Si}_3\text{AlO}_8)$, and albite ($\text{NaSi}_3\text{AlO}_8$), as compared to soda-orthoclase ($\text{NaSi}_3\text{AlO}_8$), may be attributed to the smaller volumes occupied by the O of the microcline and albite, due to their triclinic symmetry as contrasted with monoclinic symmetry of orthoclase.

The contrast in resistance of olivine (MgFeSiO_4) and zircon (ZrSiO_4) is due to the effect of tightness of packing. Olivine, one of the least resistant minerals, has a unit cell volume of $291\text{\AA}$, whereas zircon, one of the most resistant minerals, has a unit cell which contains the same number of O as olivine but which occupies a volume of only $231\text{\AA}$.

Biotite; $\text{K}(\text{FeMg})_3(\text{Si}_3\text{AlO}_{10})(\text{OH},\text{F})_2$ and Muscovite $\text{KAl}_2(\text{Si}_3\text{AlO}_{10})(\text{OH},\text{F})_2$ with the same type of tetrahedral linkage, and with the same number of alumina tetrahedrons, is an example of both volume and expansion. Biotite, which is less resistant of the two minerals, contains Fe^{2+} and a unit cell of $489\text{\AA}$, whereas muscovite does not contain Fe^{2+} and has a unit cell of $459\text{\AA}$.

Structural Differences

(i) Empty positions in parts of the structure reduce the electrostatic forces that bind the structure together. They also serve as ports of entry and departure to the interior of a crystal particle, and thereby serve to accelerate reactions, involving cations in the interior of the particle. For example, in micas, the cavities in the center of the hexagonal rings of oxygen on the bases of the tetrahedrons. Such empty positions facilitate the entry of K^+ , with other cations such as Ca^{++} Mg^{++} Na^+

or H^+ , which may alter the structure. (ii) The presence of large channel is the primary cause of low stability and of cation exchange properties of zeolites (Ca, Na, K silicates).

Stoichiometric Properties

Clay minerals have the property of sorbing cations and anions and retaining these in exchangeable state, i.e. these ions are exchangeable for other cations or anions by treatment of such ions in a water solution. This exchange reaction is Stoichiometric. This does not affect the structure of silica-alumina arrangement.

Unit Cell Exposure

Since the reactions of crystal particles during weathering occur in the unit cells exposed at their surfaces, it is expected that the smaller the percentage of unit cells of a particle exposed at the surface, the more stable is the mineral. The size and shape of the individual particle determine the percentage. For a given sized particle, the plate shaped particles have the largest percentage exposure; the rod shaped next, the cube shaped the least. It should be noted, however, that a consideration of the percentage of unit cells of a given particle is significant only in minerals that do not have channels in their structure or defects that enable solutions or ions to the interior of the particle.

Nature of Associated Minerals

The relative stability of a given mineral may be affected by the nature of the other minerals associated with it through their effect on the composition of the solution in contact with the mineral.

Cation Exchange Capacity

The higher the Cation exchange capacity of the mineral, the more readily and rapidly does adsorbed H^+ interchange with Al^{3+} and Mg^{2+} of octahedral or Al^{3+} of tetrahedral positions.

Depending on characters mentioned above, the weatheribility of few common minerals is listed below:

<i>Weatheribility of Common minerals</i>		
Easily weathered	:	Olivine, Hornblende, Augite, Biotite
Moderately weathered	:	Apatite, Anorthite, Oligoclase, Albite, Garnet, Orthoclase, Muscovite
Slowly weathered	:	Titanite, Ilmenite, Magnetite, Tourmaline, Zircon, and Quartz.

SOIL FORMING MINERALS

There are two kinds of minerals present in the soil. They are called primary and secondary. Primary minerals are those which have persisted from the original rock. Some of them remain unchanged during the course of soil formation. They are usually present in sand fraction. These minerals are formed at elevated temperatures and inherited from igneous and metamorphic rocks. Primary minerals

Table 2.2. Minerals in Earth’s crust and soil

Mineral	Earth’s crust (%)	Soil (%)
Feldspars	58	2.5
Hornblende	15	3.0
Quartz	13	44.5
Micas	4	0.5
Accessory minerals	10	Varying amounts

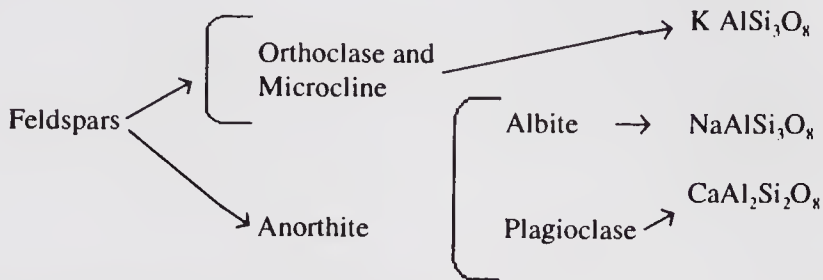
influence the elemental composition of soil and are therefore also called skeletal minerals. Primary minerals contain silicon and oxygen along with metal cations and are therefore called silicate minerals. Oxygen and silicon present in the earth’s crust combine to form silica tetrahedron (SiO_4^-). Secondary minerals are recrystallised or precipitated as solid from soluble substances. These minerals have formed from alteration and decomposition of primary minerals. These minerals include clay minerals. These minerals are formed at low temperature reactions and inherited by sedimentary rocks. The principal minerals in the earth’s crust and soil are presented in Table 2.2 and primary and secondary minerals in Table 2.3.

Primary Minerals

Feldspars: The feldspars are the most abundant minerals in the earth’s crust. They are light minerals (Sp. gr. 2.65). Feldspars are the aluminium silicates ($\text{Si}_3\text{AlO}_8^-$) of K, Na and Ca. Feldspars may be classified as follows :

Table 2.3. Primary and Secondary minerals

Primary minerals		Secondary minerals	
Mineral	Chemical composition	Mineral	Chemical composition
Quartz	SiO_2	Goethite	FeOOH
Feldspars			
Orthoclase	KAlSi_3O_8	Hematite	Fe_2O_3
Albite	$\text{NaAlSi}_3\text{O}_8$	Gibbsite	$\text{Al}_2\text{O}_3.3\text{H}_2\text{O}$
Anorthite	$\text{CaAl}_2\text{Si}_2\text{O}_8$	Kaolinite	$\text{Si}_4\text{Al}_4\text{O}_{20}(\text{OH})_8$
Micas			
Muscovite	$\text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2$	Montmo- rillonillonite	$\text{Si}_8\text{Al}_4\text{O}_{20}(\text{OH})_4$
Biotite	$\text{KAl}(\text{Mg},\text{Fe})_3\text{Si}_3\text{O}_{10}(\text{OH})_2$	Chlorite	Mg, AlSilicates
Hornblende group		Hematite	Fe_2O_3
Hornblende	$\text{Ca}_2\text{Al}_2\text{Mg}_2\text{Fe}_3\text{Si}_6\text{O}_{22}(\text{OH})_2$	Limonite	$2\text{Fe}_2\text{O}_3.3\text{H}_2\text{O}$
Olivine	$(\text{MgFe})_2\text{SiO}_4$	Dolomite	$\text{CaCO}_3.\text{MgCO}_3$
		Calcite	CaCO_3
Augite	$\text{Ca}_2(\text{Al},\text{Fe})_4(\text{MgFe})_4\text{Si}_6\text{O}_{24}$	Gypsum	CaSO_4



Feldspar consists of a continuous three dimensional network (tectosilicate structure) of silica tetrahedra where all the four oxygens of one silica tetrahedron have been shared by the silicon ions of the neighbouring silica tetrahedra (Fig. 2.2).

Some of the silicon ions (Si^{4+}) of some tetrahedra have been replaced by aluminum (Al^{3+}) ions. This develops excess negative charge, which may be satisfied by Na^+ , Ca^{++} or K^+ as evident in albite, anorthite and orthoclase respectively. Orthoclase feldspar is an important source of potassium in soils. Plagioclase feldspars provides an important relationship of degree of weathering to soil fertility. As the weathering intensity increases with time calcium supply can progressively be obtained in soils. In well weathered soils, the presence of plagioclases, i.e. albite and anorthite makes one soil productive than the other.

Pyroxenes and Amphiboles (Inosilicates)

They are ferromagnesian (minerals containing Fe and Mg) minerals. These are heavy minerals (Sp. gr. > 2.85) and predominant among the dark constituents.

Pyroxenes: Pyroxenes are the silicates of Ca, Mg, Fe, Mn and Al. They have a single chain of tetrahedron $(\text{Si}_2\text{O}_6)^{4-}$. The crystal structure consists of chains of

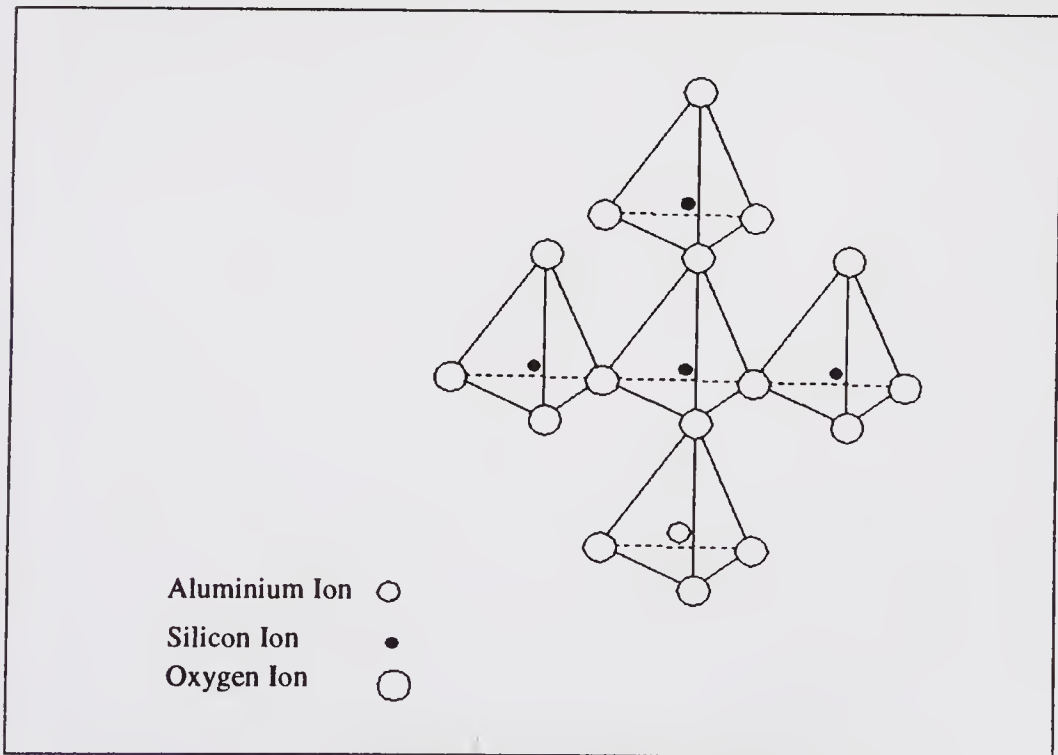


Fig. 2.2. Structure of feldspar.

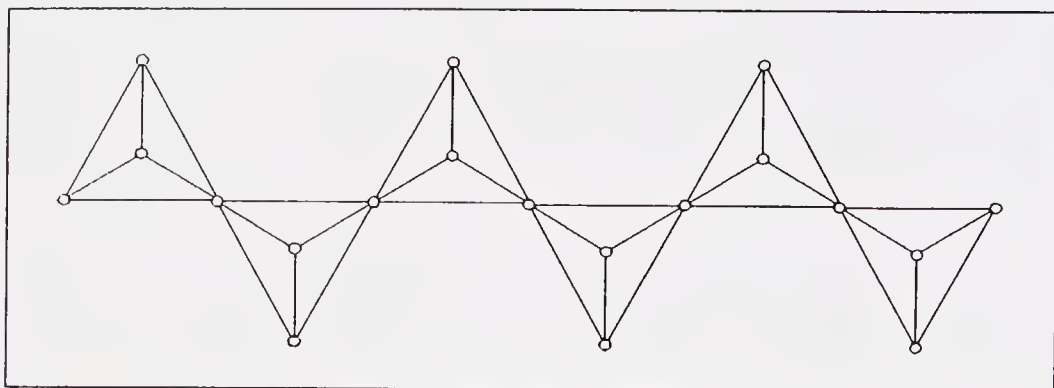


Fig. 2.3 (a) Structure of Pyroxenes

silica tetrahedrons in which two basal oxygen of each silica tetrahedron are shared by the silicon ions of another silica tetrahedra (Fig. 2.3 a).

Examples : Enstatite $\text{Mg}_2(\text{Si}_2\text{O}_6)$, Hypersthane $(\text{MgFe})_2(\text{Si}_2\text{O}_6)$, Diopside $\text{CaMg}(\text{Si}_2\text{O}_6)$ Augite $\text{Ca}_2(\text{AlFe})_4(\text{MgFe})_4\text{Si}_6\text{O}_{24}$

Amphiboles: Amphiboles consist of two chains of silica tetrahedra held together by two infinite chains. Every second and third ion of the silica tetrahedra is shared by silicon ions of the neighbouring silica tetrahedra (Figure 2.3 b). They have double chains of tetrahedrons $(\text{Si}_4\text{O}_{11})^{6-}$

Examples: Hornblende $(\text{Ca}, \text{Na})(\text{Mg}, \text{Fe})_4(\text{Al}, \text{Fe})[(\text{Si}, \text{Al})_4\text{O}]_{11}(\text{OH})_2$

The variety of substitutions possible in pyroxenes and amphiboles offers a good source of trace elements and other nutrient cations. They are easily weathered to provide significant amounts of these elements, in forms available for plants.

Olivine (Orthosilicates): Olivine consists of independent silica tetrahedra combined with iron and magnesium. Oxygen ions (their negative charge) of silica tetrahedron are thus satisfied by magnesium and ferrous ions, which link

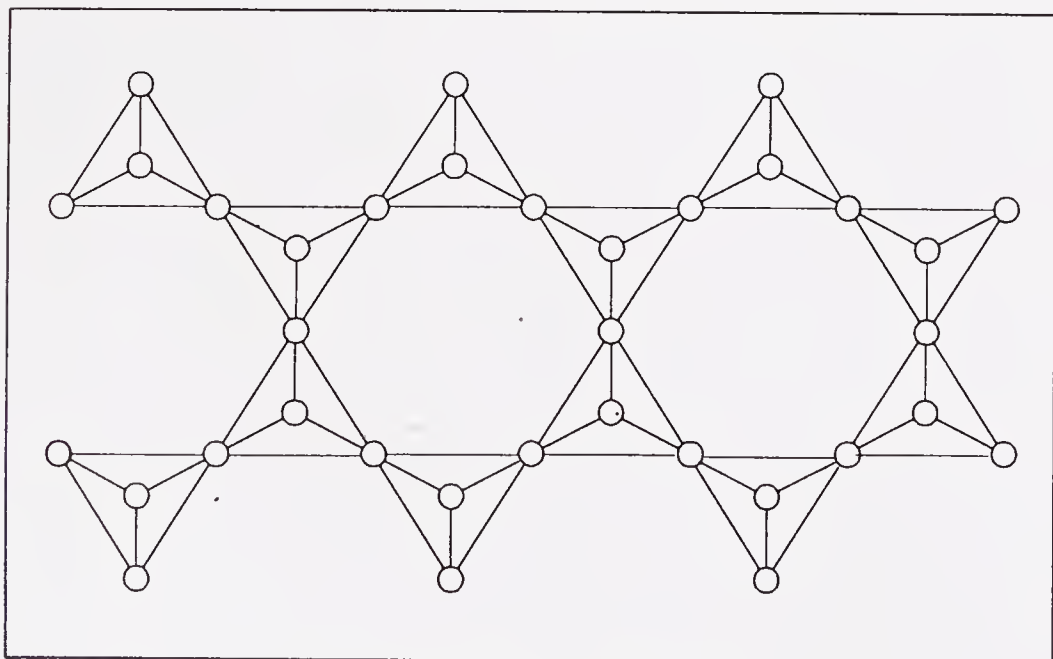


Fig. 2.3. (b) Structure of amphiboles.

tetrahedrons. Olivine's are easily weathered and yield free iron oxide and nontronite. This group of mineral contributes to the nutrient status of soils.

Quartz (Tectosilicates): The structure of quartz is a continuous framework of silica tetrahedron. All the four oxygens of the tetrahedra are shared. All the negative charges of the oxygen ions are satisfied by silicon ions. Thus quartz is chemically inert. Quartz is one of the most resistant minerals. It is the dominant mineral of the fine sand and coarse silt fraction of the soil. Pure quartz does not contain any plant nutrient and is chemically inactive. Its important forms include Opal- $\text{SiO}_2 \times \text{H}_2\text{O}$ Cristobalite- SiO_2 . (Fig. 2.4).

Micas (Phyllosilicates): Phyllosilicates include micas, talc and chlorites. Micas occur as primary minerals in igneous rocks. They also occur as secondary minerals in altered products of feldspars and other minerals. The mica minerals are the aluminosilicates characterized by a plate like structure and a perfect basal cleavage. The chief members of this group of mineral are biotite – silicates of K, Al, Mg, Fe and muscovite – silicates of K and Al. Biotite weathers more rapidly than muscovite. These minerals constitute an important source of soil potassium in addition to other cations held in interlayer spaces. Structure of micas will be dealt in discussion on clay minerals.

Secondary Minerals

Clay minerals: These minerals are present in fraction of soil less than 2 micron in diameter. They are inorganic, crystalline, and colloidal, of different colour and reactive fraction of soil. The kind of clay minerals dominant in a soil depends on the parent material and weathering intensities under which they have been formed.

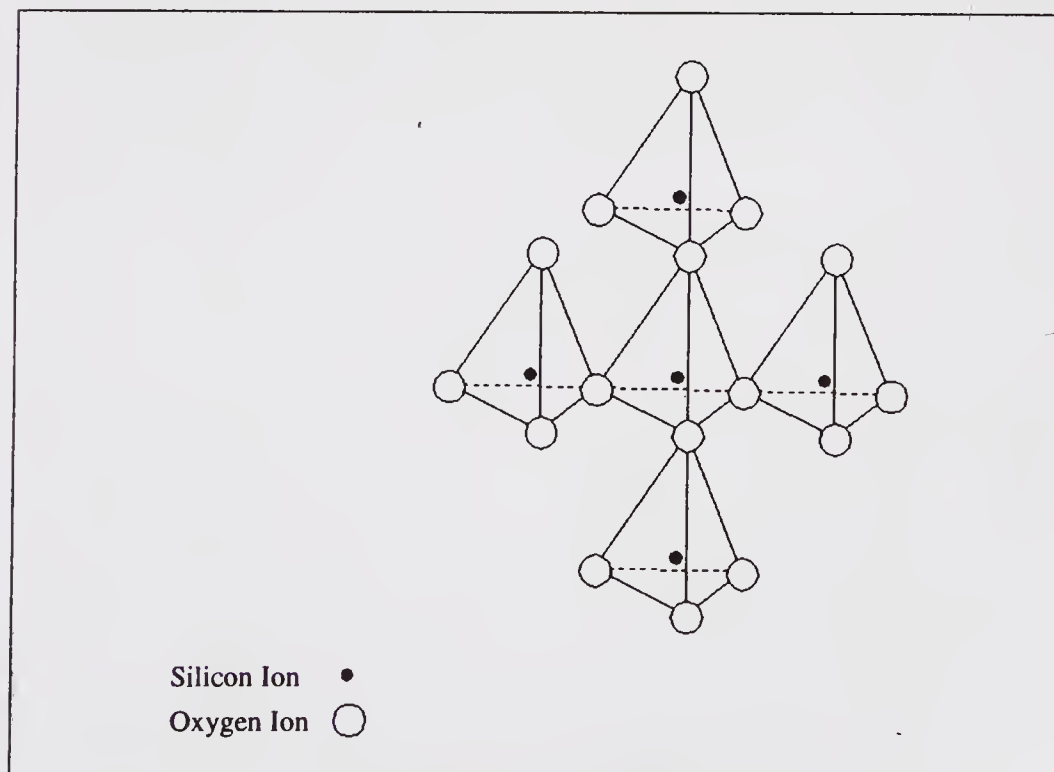


Fig. 2.4. Structure of Quartz.

Table 2.4. Non silicate minerals of common occurrence in soil and their characteristics.

Form	Mineral	Formulae	Colour	Hardness	Density	Characteristics features
Oxides	Hematite	Fe_2O_3	Red to Black cherry red streak	5-6	5 . 2	cherry red streak an important mineral of iron ore
	Lim onite	$\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$	Brownish- Yellow	1 (loose) to 5 (compact)	2.7-4.3	dehydrated to hematite, an important ore of iron
	Geothite	$\text{FeO}(\text{OH}) \cdot n\text{H}_2\text{O}$	Dark brown to yellowish-brown	5.5	3 .3-4. 3	found in the crust of weathering as a disintegration product of pyrite, magnetite, silicates
	Gibbsite	$\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$	White, with common coating of hematite and geothite	2.5-3.5	2 . 35	Coatings of hematite (red) or geothite (yellow) are common
Carbonates	Calcite	CaCO_3	White	3.0	2 . 7	common inclusion
	Magnesite	MgCO_3	White	4 - 4.5	3 . 0	in limestone
	Dolomite	CaCO_3	light brown	3.5-4	2 . 9	contains impurities
	Sidrite	$\text{MgCO}_3 \cdot \text{FeCO}_3$	brownish yellow, brown	3.5 - 4.5	4 . 0	of Fe^{2+} common under water-logged condition.
Sulphate	Gypsum	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	White or grey or pink due to impurities	2	2 . 3	Source of calcium and sulfur for plants.
Phosphates	Apatite and chlorapatite Hydrox-yapatite Oxyapatite carbonate apatite or phosphate apatite	$\text{Ca}_3(\text{PO}_4)_3$ (Cl-) (OH-) (,O=) (CO_3 =)	Yellow green white or reddish-brown or black	5	3 . 2	Common carrier of phosphorus in soil, it is present in various forms in combination with clays, CaCO_3 and Fe and Al hydrous oxides'
Halides	Rock salt	NaCl	White			

Table 2.5. Accessory minerals and their composition

Magnetite	Fe_3O_4	Zeolite	Ca Na K silicates
Pyrite	Fe S_2	Serpentine	$\text{Mg}_6(\text{Si}_4\text{O}_{10})(\text{OH})_8$
Ilmenite	Fe TiO_3	Malachite	$\text{Cu CO}_3 \cdot \text{Ca}(\text{OH})_2$
Garnet	$(\text{Ca Fe Mg Al})\text{SiO}_4$	Azurite	$2\text{Cu CO}_3 \cdot \text{Cu}(\text{OH})_2$
Tourmaline	Boro silicates of aluminium	Barytes	BaSO_4
Zircon	$\text{Zr}(\text{SiO}_4)$	Rutile	Ti O_2
Chlorapatite	$[(\text{Ca}_3(\text{PO}_4)_2)_3\text{CaCl}_2]$	Flourapatite	$[(\text{Ca}_3(\text{PO}_4)_2)_3\text{CaF}_2]$
Carbonate apatite	$[(\text{Ca}_3(\text{PO}_4)_2)_3\text{Ca CO}_3]$	Oxyapatite	$[(\text{Ca}_3(\text{PO}_4)_2)_3\text{Ca O}]$

A detailed discussion of structure and properties of clay minerals will be made in chapter on soil colloids.

Non silicate secondary minerals: These minerals occur only in small amounts. They are either inert or highly soluble in water so that from the point of soil chemistry does not form significant contributions. These minerals may be classified as in Table 2.4.

Accessory Minerals

These minerals are present in small quantities. They are present in sand and silt fractions of soils. They form a group of heavy minerals because of their high specific gravity. Accessory minerals and their composition have been given in Table 2.5.

The description of a few important accessory minerals are given below:

Tourmaline: It is a complex ring borosilicate of aluminum. Its various forms are:

Shorl: Dark blue $\text{Na,Ca Fe}_3(\text{AlFe})_6(\text{Si}_6\text{O}_{18})(\text{BO}_3)(\text{OH},\text{F})_4$

Dravite: Brown $(\text{Al,Fe})_6(\text{Si}_6\text{O}_{18})(\text{BO}_3)_3(\text{OH},\text{F})_4$

Elbaite: Pink, green or white $\text{Na}(\text{Li,Al})_3\text{Al}_6\text{Si}_6\text{O}_{18}(\text{BO}_3)_3(\text{OH},\text{F})$

Its hardness equals 7.5 - 8 and the density is 2.9 - 3.2. When the accumulations of magnesite tourmaline are abundant the mineral serves as a raw material for the production of boron.

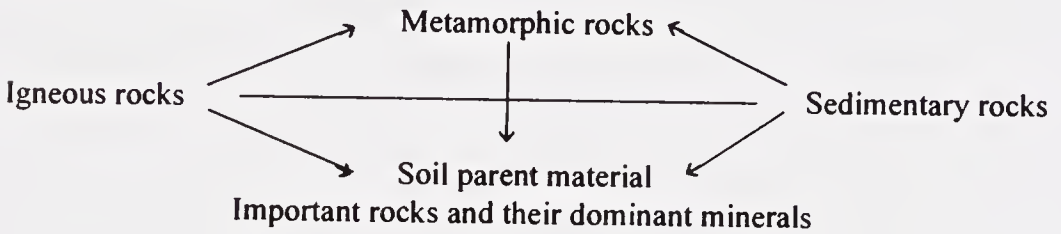
Pyrite: It contains 46% of Fe and 53.4% of S. The colour is straw yellow with black streak and a metallic lustre. Hardness is 6 – 6.5 and the density is 5. When oxidized, pyrite is transformed into the brown oxides of iron (limonite) with the retention of sulphur. Pyrite is produced through reduction of iron of ferric oxides and sulphur of sulphate. Pyrite is one of commonest sulfides in nature and formed within geological processes (common as mineral in igneous and metamorphic rocks). Pyrite is most valuable in the production of sulphuric acid. Marcasite is one of its important forms, which contains arsenic and titanium as impurities.

Rutile: It is a resistant mineral known to be inherited from igneous rocks. The colour is brownish red to black with light brown or yellow streak. Its hardness equals 6 – 6.5 and the density is 4.2. It serves as an important ore of titanium.

Zircon: It is an accessory mineral common in igneous rocks (granites and syenites). Zircon is an ore of the zirconium metal used in the production of steel. The transparent variety of zircon is called hyacinth. Its hardness equals 7.5 – 8 and density is 4.7.

ROCKS

A rock may be defined as an aggregate of one or more minerals. Solid rock breaks into smaller particles, which form parent materials of soil. Most abundant rocks on earth's surface are presented in Table 2.6. Both igneous and sedimentary rocks can be transformed into metamorphic rocks. Igneous, sedimentary and metamorphic rocks, all are weathered into soil parent material. This can be diagrammatically represented as:



CLASSIFICATION OF ROCKS

Based on the genesis and structure, rocks are generally grouped into three classes:

- | Type of rocks | Mode of formation |
|-------------------------|---|
| (i) Igneous rocks | : Originated from cooling and solidification of molten material (magma) |
| (ii) Sedimentary rocks | : Formed by sediments deposited in water and consolidated |
| (iii) Metamorphic rocks | : Igneous or sedimentary rocks changed by heat or pressure. |

Igneous rocks

These rocks are formed by solidification of molten magma from the interior

Table 2.6. Important rocks and their dominant minerals

Types of rocks	Per cent in earth's crust	Dominant minerals
i) Igneous rocks	95%	Quartz, feldspars, dark coloured minerals-biotite, augite, hornblende
ii) Sedimentary rocks Shales	4%	Clays
Sand stone, limestone	0.9%	Quartz, calcite, dolomite
iii) Other rocks	0.1%	
Metamorphic rocks like marble, Quartzite		Calcite Quartz
Slate		Clays
Gneiss and Schist		Variable composition

Table 2.7. Classification of igneous rocks based on their silica content.

Rock	Silica content	Example
Acid rocks	65 and above	Granite
Sub-acid rocks	60–65	Syenite
Sub- basic rocks	55–60	Diorite
Basic rocks	55 or below	Basalt

of the earth. Basic material of earth’s crust is igneous rocks. These are the oldest rocks by their very origin. They are named on the basis of the depth in soil where molten magma solidifies. i) plutonic, when the magma solidifies at greater depths; ii). intrusive, when it solidifies at moderate depths and iii) extrusive, when solidification takes place on the surface as a result of volcanic activities. Igneous rocks are also classified according to their content of silica (SiO₂) (Table 2.7).

Igneous rocks are described according to their colour, texture, and mineral composition, (i) Granitoid or coarse textured-composed of particles large enough to be seen with naked eye (ii) Fine textured– need a lens to distinguish the grains of rocks (iii) porphyritic-composed of larger crystals embedded in a fine matrix (iv) fragmental – rocks contain fragments (v) amorphous-rocks are non-crystalline masses. A few important igneous rocks, their characteristics and dominant minerals have been presented in Table 2.8.

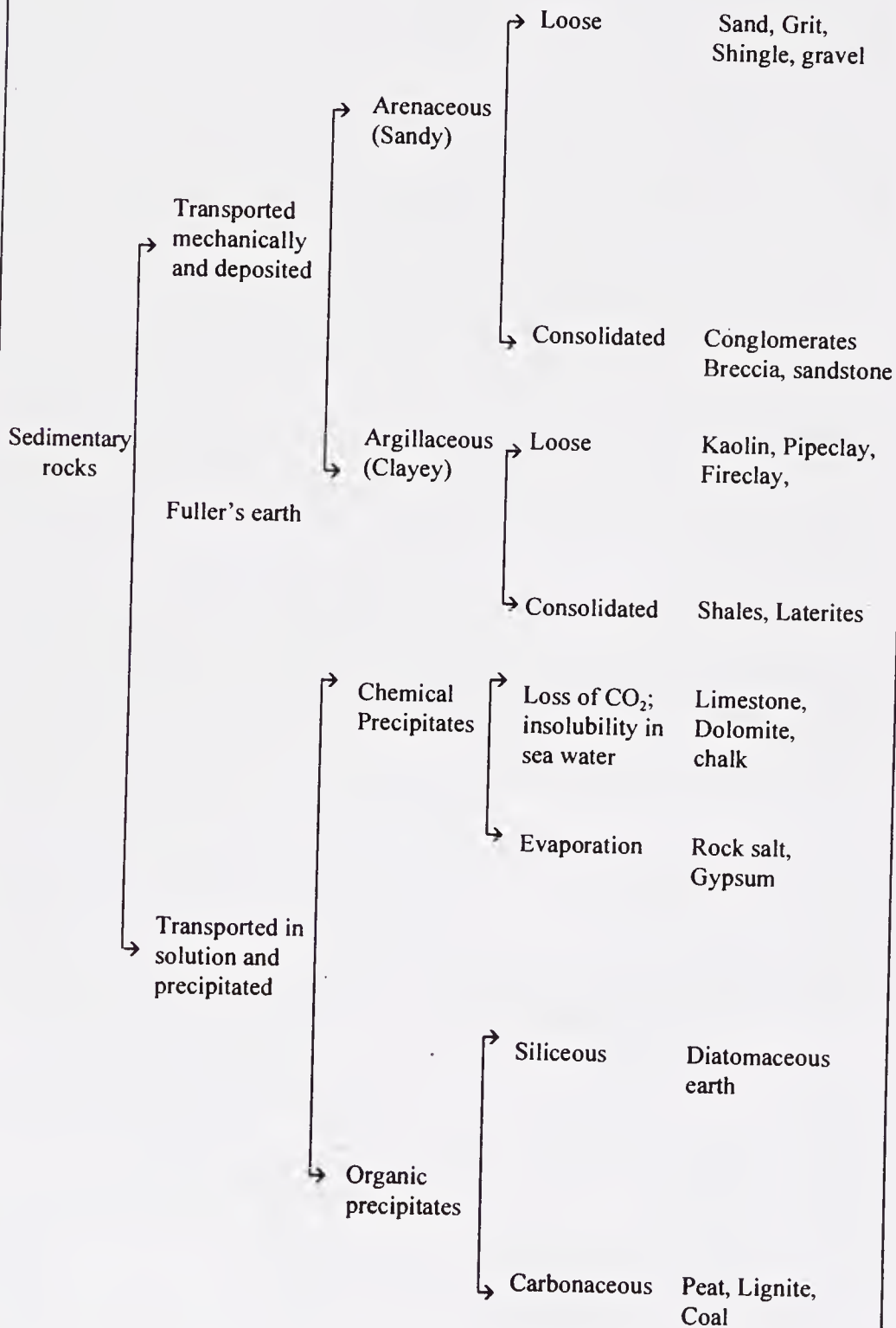
Sedimentary Rocks

These rocks are formed from deposition of sediments. These sediments are deposited through the action of wind or water on igneous or metamorphic rocks. Dissolved materials from the rocks are deposited when the water evaporates. These deposits or sediments may remain as loose material or are cemented and consolidated into sedimentary rocks. The usual liming materials are silica, lime or oxides of iron. The surface layer of rock on the earth is usually sedimentary.

Table 2.8. Important igneous rocks, their characteristics and dominant minerals

Rock	Characteristics	Dominant mineral
Granite (acidic)	Hard, massive, crystalline coarse grained, mixtures of pink and white or black and white	Orthoclase, feldspar, mica, free quartz, hornblende secondary minerals like chlorite, kaoline, apatite
Syenite (sub acidic)	Similar to granites	Contain very little free quartz
Diorite (sub basic)	Medium grained, greenish black hard rock	Plagioclases feldspar, augite, hornblende, biotite mica
Basalt (basic)	Fine grained, very compact, dark coloured, micro-crystalline texture, smooth surface.	Plagioclases feldspar, augite, magnetite
Trap	Full of cavities and vesicles	Feldspar, pyroxene, magnetite, zeolite quartz, calcite

Classification of Sedimentary rocks



Sedimentary rocks are also known as aqueous rocks as water is the main agent in their formation or stratified rocks as the sediments are arranged into layers. Classification of sedimentary rocks has been presented as follows.

Important Sedimentary Rocks and their Characteristics

Arnaceous (Sandy, Loose)

Sand, grit, shingle, gravel refer to loose fragment rocks of varying size and shape. Sand, consists of quartz grains. Grit, is sharp and angular sand. Shingle, are large rounded pebbles. Gravel, is a mixture of angular and rounded pebbles. All these are made up of quartz.

Arnaceous (Sandy, Consolidated)

It includes conglomerates, breccia and sandstone. Conglomerates and breccia are made up of various sized fragments of rocks cemented together. Sandstones are cemented sands. Lime and iron oxides are useful cementing materials. Sandstones may be siliceous-cemented with silica and hard; ferruginous-bound with iron oxide, carbonaceous-occurs along with organic matte, argillaceous-held together by clay.

Argillaceous (Clayey, Loose)

Kaolin, pipeclay, fireclay, and Fuller's earth are loose argillaceous materials. Kaolin, is formed by deposition of feldspar; Pipeclay, is iron free clay; Fire clay – is clay free from lime and alkalis; Fuller's earth - is non-plastic clay. All these are composed of aluminium silicates along with impurities.

Argillaceous (Clayey, Consolidated)

It is comprised of shales and laterites. Shales, are recemented clays and silts. This consists of close spaced layers. Shales are named according to impurities contained in them, i.e. ferruginous (alongwith iron) or bituminous (containing organic matter). Laterite rocks are composed of clay mixed with hydroxides of aluminium and iron. They are red brown with yellow spots and rough to feel.

Chemical Precipitates (Formed Due to Loss of CO₂)

Limestone, dolomite and chalk are such precipitates. These are not soluble in sea water. Limestone, consists chiefly of calcium carbonate with clays, silts and sands. Dolomite, contains magnesium carbonate. Arnaceous limestone contains sand, carbonaceous limestones are dark coloured and contains carbonised tissues of plants and animals. Chalk, is soft, light coloured rock composed of fine particle which may be seen as the skeletons of tiny single celled animals, formamifera.

Table 2.9. Classification of metamorphic rocks

Type of folia	Characteristics	Examples
Foliated	Crystalline Grains indistinct	Gneisses, Schists Slates
Non-foliated	Full of quartz, crystals very hard Effervesces with acid	Quartzites Marble

Chemical Precipitates (Due to Evaporation)

Rock salt and gypsum are precipitated due to drying up of inland lakes and seas.

Organic Precipitates

Siliceous: These rocks are composed of SiO_2 derived from plants and animals like diatoms.

Carbonaceous: These rocks are made of carbon derived from plants. Peat, is porous, soft and dark brown. Lignite and coal, are black and more compact.

Metamorphic rocks

When igneous and sedimentary rocks are subjected to great heat and pressure, they change to form metamorphic rocks. For example, limestone when subjected to heat and pressure, changes to marble, thus original rocks may not be identified. (Table 2.9 and 2.10).

Pressure: As a result of pressure, the rocks are flattened and they are called folia, i.e. thick in the middle and thin at the edges, such rocks are called foliated rocks. When the folia are not separate, the rock is called gneiss. If the rock crystals

Table 2.10. Important metamorphic rocks, their characteristics and dominant mineral

Rock	Characteristics	Dominant mineral
Gneisses (foliated rock)	(i) Consists of alternate layers or band of light and dark coloured minerals (ii) named-according to their original rock-granite gneiss.	Hornblende, biotite (dark coloured) Quartz feldspar, (light coloured).
Schists (foliated rock)	(i) includes tubular flaky or fibrous minerals (ii) their layers are separable at a distance of 0.5 cm approx. (iii) named according to mineral most abundant in them mica schist, quartz schist, chlorite schist, talc, schist, hornblende schist.	mica hornblende chlorite
Slates (foliated rock)	(i) slates are formed from shales, it has slaty cleavage, it can be broken along its parallel planes. (ii) It is fine grained made up mainly of clay, usually black or grey coloured, but others like red also occur.	clays (Hardened shale) recemented clay, a sedimentary rock.
Quartzites (non-foliated rock)	(i) formed by the action of heat on sandstones. (ii) It consists of fine granular mass which may be stained red, brown or yellow depending upon the nature of impurities.	Quartz
Marble (Non-foliated rock)	(i) Pure marble is white in colour, but may be of different colours due to presence of impurities.	Calcite, dolomite

are flattened and the folia are easily separable, the rock is called schist.

Heat: Heat caused by volcanic lava can melt the original rocks. Thus sandstones become quartzite.

Water: Water in combination with heat and pressure can bring about chemical changes.

References and Suggested Readings

- Bear, Firman (1964). *Chemistry of the Soil*. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi.
- Means, R.E. and Parcher, J.V. (1965). *Physical Properties of Soils*. Prentice Hall of India Pvt. Ltd.
- Narayan, N.S. and Shah, C.C. (1966). *Physical Properties of Soils*. Helma Text Books, Manaktalas Bombay.
- Rankama, K. and Sahana, Th. (1950). *Geochemistry*. University of Chicago Press, Chicago.
- Sinha, R.K. (1975). *An Introduction to Geology*. Vikas Publishing House Pvt. Ltd., New Delhi.

QUESTIONS

Q. 1. Fill in the blanks

- i) Most minerals with a metallic lustre are good conductors of _____ and _____.
- ii) Mineral _____ when broken separates in certain definite directions along plane surfaces, a property called fracture.
- iii) Minerals may be classified as light or heavy depending upon their _____.
- iv) The _____ the volume occupied by a given number of oxygen's, the more stable is the mineral.
- v) The presence of large channels is the primary cause of low stability of cation exchange properties of _____.
- vi) The structure of _____ is a continuous chain of silica tetrahedral
- vii) _____ is a complex ring borosilicate of aluminium.
- viii) Pyrite contains _____ % iron and _____ % sulphur.
- ix) _____ is non-plastic clay.
- x) Chemical composition of olivine may be represented by formulae _____.

Answers

(i) heat and electricity (ii) calcite (iii) specific gravity (iv) smaller (v) zeolites (vi) quartz (vii) tourmaline (viii) 46 and 53 (ix) fuller's earth (x) $(\text{Mg Fe})_2 \text{SiO}_4$

Q. 2. Choose the correct answer

- i) Quartz has a hexagonal/ tetragonal crystal form.
- ii) Olivine has a trimetric/triclinic crystal form.

- iii) Graphite and pyrite have a metallic/ non metallic lustre.
- iv) Feldspars/ micas are the most abundant mineral in the earth's crust.
- v) Pyroxenes and amphiboles are heavy/ light minerals.
- vi) Basic material of the earth's crust are igneous/ sedimentary rocks.
- vii) Slates are formed from shales/ limestone.
- viii) Quartzites are non-foliated/ foliated rocks.
- ix) Hornblende/ orthoclase are easily weathered.
- x) Quartz is classified as a tectosilicate/ phyllosilicate mineral.

Answers

(i) hexagonal (ii) trimetric (iii) metallic (iv) feldspars (v) heavy (vi) igneous (vii) shales (viii) non-foliated (ix) hornblende (x) tectosilicate

Q. 3. Define the following

(i) Mineral (ii) Specific gravity of a mineral (iii) Hardness of a mineral (iv) Accessory minerals

Q. 4. Differentiate between

(i) Rock and Mineral (ii) Light and Heavy minerals (iii) Biotite and Muscovite (iv) Pyroxenes and Amphiboles (v) Primary and Secondary minerals (vi) Argillaceous and Argillaceous sedimentary rocks (vii) Gneiss and Schist

Q. 5. Write short notes on

(i) Radioactivity of minerals (ii) Stoichiometric properties of clay minerals (iii) Feldspars (iv) Olivines (v) Resistant minerals (vi) Laterite rocks

Q. 6. Comment on the following statements

- i) More constant than the colour of a mineral is the colour of its powder
- ii) Aluminosilicates predominate in soil
- iii) The presence of Al^{3+} in the tetrahedral position impart aluminosilicate mineral instability
- iv) Mineral with structure containing Mg^{2+} and Fe^{3+} are more stable than those containing Al^{3+} and Fe^{2+}
- v) Minerals differ in their order of crystallization
- vi) Microcline is more resistant than orthoclase
- vii) The resistance of olivine and zircon differs
- viii) Plagioclases makes one soil more productive than the other
- ix) Quartz is chemically inert

Q. 7. Answer the following in brief

- i) Enlist the hardness of minerals as devised by Mohr
- ii) Classify minerals, based on their chemical composition
- iii) Classify minerals on the basis of silica and alumina linkages
- iv) Classify minerals according to their weatherability
- v) Enlist five primary and five secondary minerals with their formulae
- vi) Enlist four igneous rocks and minerals dominant in them
- vii) Enlist six non-silicate minerals with their formulae

Q. 8. Answer the following in detail

- i) Explain different crystal forms and their characteristics. Also give examples
- ii) Describe factors affecting stability of minerals
- iii) Classify sedimentary rocks

Q. 9. Give diagrammatic view of the following

- (i) Crystal forms of minerals (ii) Structure of feldspars (iii) Structure of pyroxenes and amphiboles.



3

Weathering of Rocks and Minerals

WEATHERING refers to disintegration and decomposition of rocks and minerals. Weathering leads to the formation of regolith (unconsolidated residues of the weathered rock on the earth's surface or above the solid rock). This develops parent material over which soil formation takes place. Parent material may be defined as chemically weathered mineral material from which soils are developed. Soil formation is caused by the action of atmospheric agents at or near the surface of the earth. When the rocks and minerals are exposed to the action of atmospheric agents, the new compounds so formed are in equilibrium with the changed environment. The compounds so formed are more stable. For example (I) formation of clay in soil (II) formation of hydrated aluminium silicates and free silica as a result of decomposition of feldspars.

Weathering processes are basically physical and chemical. Physical weathering leads to disintegration. Disintegration causes decrease in size of rocks and minerals and there is no change in the chemical composition of the substance so formed. Chemical weathering results in decomposition. During decomposition definite chemical changes take place and new minerals may be synthesized. Biological agencies accelerate physical and chemical weathering.

WEATHERING – A CONSTRUCTIVE AND DESTRUCTIVE PROCESS

Weathering is a combination of destruction and synthesis. Rocks are first broken down into smaller particles of which they are composed (destructive processes). The minerals are attacked by chemical forces and are changed into new minerals either by minor or complete chemical changes. These changes result in decrease in particle size and release of soluble constituents. The soluble constituents may either be lost in drainage waters or recombine to form new minerals (constructive process).

Weathering Processes

There are three processes of weathering, i.e. physical, chemical and biological. Both these processes are supported by biological agencies. All these processes work simultaneously. Another supports the work of one and there is a continuous chain of reactions.

PHYSICAL WEATHERING

Physical weathering breaks down the rocks into smaller pieces without changing their chemical composition. It consists merely of the breaking of larger

fragments of rocks and minerals into finer and finer particles. This is called disintegration. No new substances are formed. Disintegration increases the exposed surface of the solid. For example, the surface area of a cube with side 'X' is $6x^2$. If now the cube is cut into a number of equal sized cubes each having a length of the edge 'Y', then the total number of cubes are X^3/Y^3 , each with an area of $6Y^2$. Therefore, the total exposed area now possessed by the same amount of matter in the original cube, would be $x^3/y^3 \times 6y^2/1 = 6x^3/y$. Thus, the new surface area is directly proportional to the cubic power of the side of the original cube and inversely to the length of the side of the new small cube. Thus if $x=1$, surface area = 6, and if y (i.e. length of the new cube as a result of dividing the original cube) be 0.5, 0.1, 0.01 and 0.001 the new surface will be 12, 60, 600 and 6000 respectively (solution: $6x^3/y$, i.e. $6 \times (1)^3/0.5 = 12$ and so on). Further, the subdivisions may form spheres, plates or rods. The enormous increase in surface area due to subdivision is thus evident.

Disintegration is an important aid to decomposition since it exposes increased surfaces to chemical action. Soil consists of coarser material under the influence of physical weathering, such soils are called skeletal soils. The physical condition of the rock and the state of consolidation determine the rate at which rocks weather. Sand stone (coarse texture, porous) will weather more easily and rapidly than a fine textured basalt. Fine deposits of unconsolidated volcanic ash weather quickly as compared with unconsolidated coarse deposits such as gravels. The principal agents of physical weathering are: (i) temperature (ii) water (iii) wind.

Temperature

The variations of temperature greatly influence the disintegration of rocks. Rocks are made up of several minerals, each with its own coefficient of expansion. Due to diurnal changes (changes in temperature of day and night) the surface of a rock weakens since the rocks do not conduct heat easily. Thus, temperature of a rock at its surface is very different from that of the part beneath. This causes the surface layer to peel away from the parent mass. This phenomenon is called exfoliation.

Differential expansion and contraction of adjacent minerals due to variations in temperature causes them to split apart. For example, expansion of quartz is twice that of feldspars. The dark colored minerals are subjected to fast changes as compared with light colored minerals. Besides, high temperature accelerates the process of weathering especially in humid regions.

Water

Water acts as disintegrating, transporting and depositing agent. Flowing water grinds the material it carries and transports them over long distances. Water loaded with such materials has tremendous cutting power. The excavation and destructive action of water is called denudation. The amount of material carried by water varies as the fifth power of its velocity, while the size of material carried varies as the sixth power of its velocity. Thus doubling the velocity increases the amount of material carried ($2^5=32$) 32 times and the size of the material by ($2^6=64$) 64 times.

i) When the rocks are ground to a very fine state, a thin film of water attaches

itself to the particles, reducing their specific gravity. Dry soil has a specific gravity of 2.65. But fine particles of 0.001 mm diameter with a film of water 0.01 mm thick have a specific gravity of 1.002 only, which is so near the specific gravity of water itself, that such fine particles when in water, remain suspended indefinitely and are easily transported over long distances by running water.

- ii) Waves, the running water near the coasts, carry sediments and are powerful grinding agents.
- iii) Glaciers, are the mountains of ice of varying sizes, several thousands of feet in thickness and width and up to 50 miles in length. Glaciers, during their movement cause a great deal of cutting and crushing of the bedrocks. In India, glaciers are found in the Himalayas.
- iv) When water freezes in rock joints and crevices, it expands to about 9 per cent of its volume, with a force of 1465 Mg/m² (150 tonnes/ft²). Freezing and thawing cause this. This exerts an enormous outward pressure and breaks the rocks.
- v) In dry weather, montmorillonite clays shrink forming large cracks. On wetting, it swells, thus alternate wetting and drying on clay-enriched rocks makes them loose and the rock breaks.

Wind

- i) Wind carrying dust, sand and gravel, grind away the surfaces of rocks. This is like sandblasting (reduction in the size of individual mineral grains by abrasion common in deserts). At a velocity of 5 m/s, particles of 0.25 mm size are transported, while at a velocity of 10 m/s, wind may carry particles of 1 mm in size. During an ordinary breeze 1 cubic mile of air carries 250 tonnes of dust, while in the heavy dust storm, there will be 125,000 tons of material in the same volume of air.
- ii) Sand storms in the deserts and high winds on the seashore have both erosive and transporting action. The shifting of soil causes wind erosion and may render cultivated land as degraded, for example, sandy deserts of Rajasthan.

CHEMICAL WEATHERING

Chemical weathering includes those processes whereby oxygen, water, carbon dioxide and nitric acid of atmospheric origin, and carbonic and organic acids of biological origin react with the minerals of the soil. Chemical weathering causes decomposition of minerals. Decomposition produces definite chemical changes in the nature and composition of rocks and minerals. Chemical weathering causes dissolution and structural changes of minerals. It results in the disappearance of certain minerals and formation of secondary products. Chemical weathering taking place in the lower layers is termed geo-chemical weathering whereas that taking place at or near the surface is termed pedo-chemical weathering.

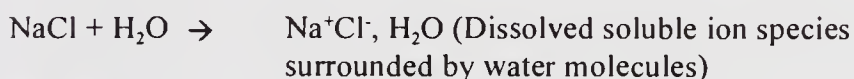
Chemical weathering becomes effective as the surface area of the rock increases. The smaller the fragments, the greater the surface area per unit volume of soil. Besides, it depends on the chemical composition of rocks for example

mineral like quartz (SiO_2) is inert and dark colored, minerals having iron and magnesium are quickly subjected to changes for example olivine $(\text{Fe, Mg})_2\text{SiO}_4$.

Water is necessary for chemical weathering. Increase in temperature increases rate of chemical weathering. Thus, chemical weathering reaches its minimum in desert areas due to lack of water and in cold regions due to low temperature. The intensity of chemical weathering reaches its maximum in tropics where both water and temperature conditions are more favorable. The principal agents of chemical weathering are 1. solution, 2. hydrolysis, 3. hydration, 4. oxidation, 5. reduction, and 6. carbonation.

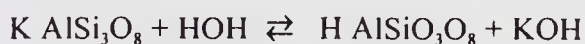
Solution

- i) The property of a substance to dissolve thus dissociating solid materials into independent soluble ions, each surrounded by liquid molecules is known as solution. Thus it facilitates rapid chemical changes since salts ionise when in contact with water.
- ii) Water is a universal solvent. Its solvent action is increased by the presence of carbon dioxide and organic acids. Carbon dioxide is absorbed from the atmosphere or from soil air. Microbial action on soil organic matter produces large quantities of carbon dioxide. Soil air contains 4000 parts of CO_2 per million parts by weight in ordinary soils to 50,000 parts of CO_2 per million in humus rich soils.
- iii) The action of solution is enhanced by acids from different sources for example natural water also contains HNO_2 and HNO_3 from the atmosphere. Soil minerals produce H_2SO_4 and H_3PO_4 . Decaying organic matter produces organic acids. Solution thus facilitates a continuous removal of constituents from the rocks in dissolved or dispersed state. Solution may be represented as follows:



Hydrolysis

Hydrolysis depends on the partial dissociation of water into H^+ and OH^- ions. At ordinary temperature one mole of water contains 1×10^{-7} moles of hydrogen in the ionic form ($\text{H}_2\text{O} = \text{H}^+ + \text{OH}^-$). H^+ -ion concentration increases in presence of CO_2 , mineral and organic acids in water solution, resulting in the accelerated hydrolytic action of water. Hydrolysis acts as a double decomposition process, which may be expressed by the following equation:



The hydroxides so formed are more soluble than the original mineral. The main processes of weathering during hydrolysis can be summarised as follows:

- (i) Some products like chlorides and sulphates are very soluble in water, appear in soil solution and move with it.
- (ii) Other products like Na, K, Hg, Ca present as exchangeable bases are relatively removed if leaching takes place,

(iii) Silica is produced and may be deposited in lower layers (as in arid regions) or may go out of the soil (as in humid regions).

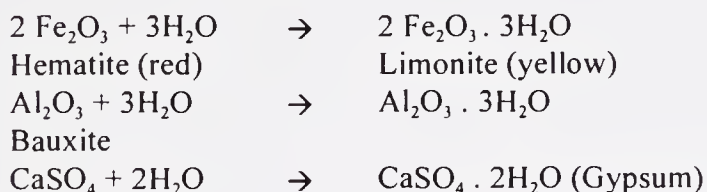
(iv) Hydrated iron and aluminium oxides accumulate and are deposited on the surface of the soil (being relatively insoluble). They may recombine with silicic acid and form secondary complexes or clay minerals.

Thus, hydrolysis is one of the most important processes in chemical weathering and may be considered as the forerunner for clay formation. An example of change of a primary soil mineral is presented below:



Hydration

- i) Chemical combination of water molecules with mineral is called hydration. Minerals like feldspars, pyroxenes, amphiboles and mica become hydrated.
- ii) Hydration results in an increase in volume, minerals become soft and more readily weatherable. Under drier conditions, the process may be reversed. Addition of water reduces bonding and hardness of minerals.



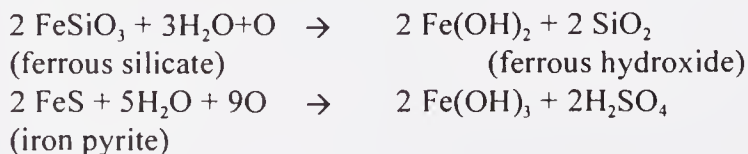
Oxidation

- i) Oxygen is present in abundance (21%) in the atmosphere. Since rocks are exposed to atmospheric air, oxygen readily combines with minerals in rocks. Oxygen is an active element and freely combines with other elements. Oxidation involves addition of oxygen to various minerals or removal of electrons from ions of higher charge for example ferrous iron loses an electron to become ferric iron.

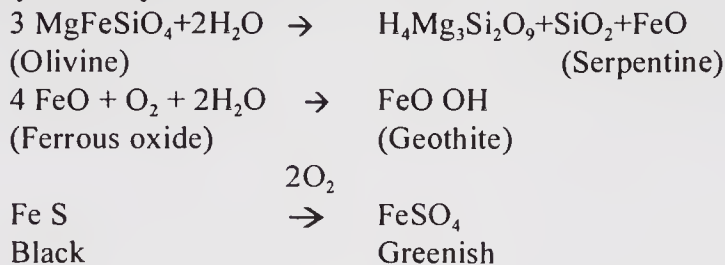
- ii) There is an increase in volume of oxidized minerals. The change in oxidation number causes imbalance in the electrical neutrality of mineral. Water and carbonic acid can rapidly attack upon such a mineral. Soil minerals containing iron, manganese and sulfides are more subjected to oxidation.



- iii) Ferromagnesian minerals contain ferrous iron which are easily oxidized to ferric iron.

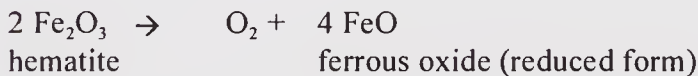


- iv) Ferrous iron may be released from the crystal, and oxidized to ferric form. For example, hydration of olivine and the release of ferrous oxide, which may be easily oxidized to ferric oxide.



Reduction

- i) Reduction is reverse of oxidation, i.e. there is gain of electrons. This results in an increase in the negative charge and the positive charge is decreased.
- ii) Oxidation-reduction properties cause structural changes in mineral.
- iii) Reduction takes place under anaerobic conditions, as in stagnant water conditions. Iron and polyvalent elements are reduced to more labile forms and are likely to be lost by leaching.



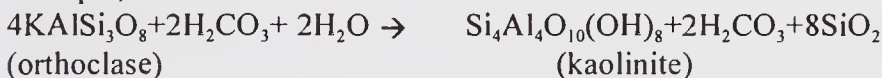
- iv) Thus colour of the mineral may change as ferric iron is converted into ferrous iron compounds. The oxidation reduction processes occur in soil minerals containing Fe, Mn and S.

Carbonation

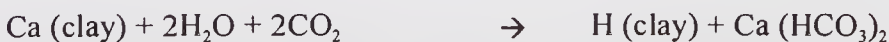
- i) The reaction of a compound with carbonic acid is called carbonation. It results in the formation of carbonate and bicarbonates. The carbon-dioxide gas combines with water forming carbonic acid and forms soluble bicarbonates as follows :



example,



- ii) Although the atmosphere contains 0.3 per cent CO_2 , rainwater may contain as high as 0.45 per cent CO_2 . Acid clays are formed by the action of CO_2 and water with clays



These acid clays are powerful extractors of cations from minerals and hence play an important role in weathering.

BIOLOGICAL WEATHERING

Biological weathering includes effect of 1) plants 2) man and animal and 3) microorganisms. Biological agents like plants, animals and microorganisms indirectly bring about physical and chemical weathering. Plants, animals and microorganisms leave many organic substances in soils during the course of their life cycles.

Plants

- i) Plants play important role in soil crumbling. Roots can exert pressure up to 10.58 kg./sq. cm. when growing into a crack in rock. Lichens can grow on bare rocks. Lichens form mild acid, which reacts with minerals to help break down of rocks. When a small amount of soil forms in rock crevices, plants begin to grow, continuing the cycle. Algae, mosses and lichens keep rocky surface moist and help chemical weathering.
- ii) All plants excrete carbonic and other acids which decompose the minerals and cementing material in rocks and bring about their disintegration.
- iii) The grass roots conserve moisture and check erosion. Deep roots may open drainage channels and promote weathering.

Man and Animal

- i) Rocks are disintegrated by human activities. Construction of dams, channels, roads and buildings causes disintegration of rocks.
- ii) Physical process of weathering is accelerated by tillage operations.
- iii) Burrowing animals like rodents and rats expose rocks for weathering.
- iv) Earthworms and ants mix up the soil with plant and animal residues and thus help chemical weathering. Earthworms add large quantities of soil material through their bodies amounting to as much as 4 tons of soil per hectare.
- v) Termites excrete formic acid and expose soil materials in tropical and subtropical regions.

Micro-organisms

- i) The lower forms of plants and animals like mosses, bacteria, fungi, actinomycetes etc. play an important role in mineral decomposition. A number of microorganisms are capable of decomposing many minerals like silicates, phosphates and carbonates.
- ii) Microbes produce CO_2 and organic acids with their activities on plant and animal residues and thus accelerate chemical weathering.

CLASSIFICATION OF PARENT MATERIALS

The exposure of rocks to the action of weathering agencies lead to the development of weathered product i.e. parent material. Two groups of parent material are distinguished.

Sedentary (formed in place)

Transported (carried somewhere else by different agencies)

They may be further classified as follows:

Sedentary

- (a) at original site – Residual
- (b) developed from plant residues –Cumulose

Transported

- (a) by water – Alluvial (flood plain terraces, delta)
 - Marine
 - Lacustrine
- (b) by gravity – Colluvial
- (c) by ice – Glacial (till moraine) out wash plains.
- (d) by wind – Eolian

These terms relate only to the placement of the parent materials. Such naming of soils cannot have any significance as the same debris deposited with differing climatic condition give rise to quite different soils. Even under the same climatic condition and with similarity of parent material, soil profiles with great diversity may be produced due to differences in topography, vegetation drainage and depth.

Sedentary (formed in place)

Residual: These materials develop very slowly in place from the underlying rocks. Igneous, sedimentary and metamorphic rocks constitute such materials.

Cumulose: These materials have developed in place from plant residues under conditions of high water table. For example, peat and muck soils.

Transported (by water)

Alluvial: These materials have been deposited by flowing water, such as rivers. If the material along the riverbanks is subjected to periodic flooding and is deposited near by it is known as flood plains. Older deposits formed by rivers are called terraces. As the flowing water continues its way, finer and finer particles are deposited at its mouth. Such materials, which are usually clayey in nature, are called delta. Alluvial soils are of great agricultural importance and are very fertile. Example: Indo-Gangetic plains of India.

Marine: These deposits are normally sandy and occur near the seashore. They are more worn and carry less mineral nutrients. By proper use of fertilizers, it is possible to raise crops on such lands.

Lacustrine: These are mineral sediments deposited in fresh water.

Colluvial: These are deposits of rock and soil resulting from sliding down of the material along slope. These materials are deposited under the force of gravity.

Glacial: These are the rock materials deposited directly by the ice masses. In Polar Regions, where ice is formed such materials accumulate. In moving across rocks moving ice carries sediments (sand silt and clay particles). During summer, ice front melts and sediments are deposited. When the ice front melts faster than it advances, a larger and smoother depression results, known as till plains. Water released with a force from a melting ice carries coarse sand particles and deposits them in a level plain. These are called outwash plains.

Eolian: Wind laden deposits are called eolians. The most common wind

deposits are the loess and sand dunes. Loess, is silt in character, varies from few meters to hundred of meters, yellowish buff in color and of uniform composition. Sand dunes occur in deserts where the sand is blown from place to place in heaps. Volcanic dust thrown by volcanoes is carried by wind over long distances.

References and Suggested Readings

- Birkeland, P.W. (1974). *Pedology Weathering and Geomorphic Research*. Oxford University Press, New York.
- Gilluly, J., Waters, A.C. and Woodford, A.O. (1959). *Principles of Geology*, 2nd edn. W.H. Freeman and Co., San Francisco.
- Kellogg, C.E. (1941). *The Soils that Support Us*. The Macmillan Co., New York.
- Marill, G.P. (1897). *A Treatise on Rocks, Rock - Weathering and Soils*. The Macmillan Co., New York.
- William, L.S. and Judson (1968). *Introduction to Geology*. Prentice Hall, New Jersey.

QUESTIONS

Q. 1. Fill in the blanks

- (i) Biological agencies accelerate physical and _____ weathering.
- (ii) The excavation and destructive action of water is called _____.
- (iii) Dry soil has a specific gravity of _____.
- (iv) Reduction in the size of individual mineral grains by abrasion common in desert is like _____.
- (v) At ordinary temperature one mole of water contains _____ moles of hydrogen ion in the ionic form.
- (vi) The reaction of a compound with carbonic acid is called _____.
- (vii) Soil minerals containing _____ and sulfur are more subjected to oxidation reduction reactions.
- (viii) The materials developed in place from plant residues under conditions of high water table are called _____.
- (ix) The mineral sediments deposited in fresh water are called _____.
- (x) When water freezes, it expands to about _____ percent of its volume.
- (xi) Oxidation of ferrous oxide leads to formation of mineral _____.

Answers

(i) chemical (ii) denudation (iii) 2.65 (iv) sandblasting (v) 1×10^{-7} (vi) carbonation (vii) iron manganese (viii) cumulose (ix) lacustrine (x) 9 (xi) hematite

Q. 2. Choose the correct answer

- (i) Doubling the velocity of water increases the amount of material carried 32 times/ 64 times.
- (ii) High temperature accelerates the process of weathering especially in humid/ arid regions.
- (iii) Chemical weathering becomes effective as the surface area of the rock increases/ decreases.
- (iv) Water is necessary/ not necessary for chemical weathering.

- (v) Oxidation involves removal/addition of electrons.
- (vi) Crops can/ cannot be raised on marines.

Answers

- (i) 32 times (ii) humid (iii) increases (iv) necessary (v) removal (vi) can.

Q. 3. Define the following

- (i) Weathering (ii) Regolith (iii) Parent material (iv) Exfoliation (v) Eolians

Q. 4. Differentiate between

- (i) Disintegration and Decomposition (ii) Physical and Chemical weathering (iii) Geochemical and Pedochemical weathering (iv) Hydrolysis and Hydration of minerals (v) Oxidation and Reduction of minerals (vi) Sedentary and Transported parent material (vii) Flood plains and Delta (viii) Loess and Sand dunes

Q. 5. Write short notes on

- (i) Skeletal soils (ii) Solution as an agent of chemical weathering (iii) Glacial deposits

Q. 6. Comment on the following statements

- (i) Weathering is a combination by both the destructive and the constructive processes
- (ii) Disintegration increases the exposed surface of the solid
- (iii) The physical condition of the rock and the state of consolidation determine the rate at which rocks weather
- (iv) The dark colored minerals are subjected to fast changes as compared with light colored minerals
- (v) Chemical weathering reaches a minimum in desert and cold regions
- (vi) Hydrolysis may be considered as the forerunner of clay formation
- (vii) Hydrolysis acts as a double decomposition process

Q. 7. Answer the following in brief

- (i) What is effect of water on specific gravity of finer soil particles
- (ii) How does the transporting action of wind cause weathering
- (iii) Illustrate the conversion of orthoclase to kaolinite
- (iv) How acid clays can be formed through carbonation

Q. 8. Answer the following in detail

- (i) Explain the role of biological agents in accelerating weathering
- (ii) Even under the same climatic condition and with similarity of parent material soil profiles of great diversity may be produced. Explain giving examples

Q. 9. Give diagrammatic view of the following

- (i) Surface area effect represented by a cube



4

Soil Formation

Soil Formation Comprises Two Distinct Processes

Weathering: It refers to the changes from rock to the development of loose mass.

Profile development: It includes changes occurring within the loose mass.

Weathering, is the disintegration and decomposition of rocks giving rise to loose and unconsolidated material, called regolith. The development of soil takes place by the combined action of soil forming factors and processes. The reactions affected by soil forming factors are additions, losses, and transformations, translocations and homogenization that occur constantly.

Additions through materials like fertilizers, organic residues, water, energy from sun. Losses result from erosion, water losses, denitrification and carbon losses. Transformations occur because of chemical and biological changes in soil system. Translocation, of substances takes place during profile development. Homogenization, through plant roots, burrowing animals, earthworms, erosion and cultivation disrupt the formation of horizons.

Any soil property is a collective function of all soil forming factors. Jenny (1941) expressed this in the following equation:

$$S = f (Cl, b, r, p, t \text{ _____})$$

Where, S = any soil property; f = is a function of, Cl = climate, b = biosphere, r = relief, p = parent material, t = time

Soil formation is slow and complex process. It is impracticable to study the cause and effect of a factor independently. Thus soil differences cannot be attributed to one factor alone when the others are simultaneously operating. In arid regions, parent material plays an important role in soil development. On the other hand, in warm and humid regions, soil characteristics are dominated by environmental factors.

Weathering processes are primarily destructive and change the consolidated rock into unconsolidated parent material. Soil formation is constructive process and results in the development of a soil profile. Soil forming factors may be active or passive.

PASSIVE AND ACTIVE FACTORS OF SOIL FORMATION

Passive Factors

They represent the source of soil forming mass and conditions affecting it. It includes parent material, relief and time.

Active Factors

They represent agents that supply energy that act upon the mass for processes of soil formation. It includes climate and biosphere.

PARENT MATERIAL AS A FACTOR OF SOIL FORMATION

Jenny (1941) defined parent material as the initial stage of soil system. Soil profiles develop from parent material:

Same type of parent material forming different soils: A given parent material may form different soils depending on environmental conditions, particularly climate and vegetation. However, the kind of soil that develops depends in part upon the kind of parent rock and parent material. Parent material, have different rates of weathering depending upon the type of rock and minerals contained in them and they generate different type of soils. A few example are as follows:

- a) Development of red and black soils within the same climatic region in south India is because of differences in chemical composition of their parent materials.
- b) Red soils are formed from rocks containing orthoclase feldspars and black soils are derived from rocks containing lime, soda feldspars.
- c) Quartz rich rocks like granites and sandstone yield more sandy material while limestone and basalt yield clayey material.

Different parent materials forming similar soils: Sometimes different parent materials may give rise to soils, which do not differ much in their properties. For example, black soils of India developed from basalt limestone, granite, gneiss under similar climatic conditions do not differ much in their physical and chemical properties.

Elements released during weathering of parent material: The amounts and type of elements released during weathering plays a specific role in soil formation. For example, calcium and magnesium are flocculating agents whereas sodium and potassium are dispersing agents. Iron and manganese impart red color to soils.

Parent material and stage of soil development: The effect of parent material on soil is stronger in the early stages of soil formation. With excessive leaching and advanced development, the influence of parent material on soil characteristics gradually decreases. Those soils where the composition of parent material dominates soil characteristics are called Endodynamorphic soils. On the other hand, when soil characteristics are controlled by the influence of climate and vegetation, a normal soil profile is developed, such soils are called Ectodynamorphic soils.

Parent material and soil reaction: Acidic conditions developed due to leaching of bases favour formation of kaolinitic clay minerals. Retention of bases favours formation of illite and montmorillonite type of clay minerals.

The influence of material on plant nutrients: Parent material is the main source of many plant nutrients. Limestone and dolomite weather to form dark colored clayey soils rich in plant nutrients. If however, dolomite are washed down by high rainfall and quartz and iron oxide are left as impurities, sandy soils poor

in plant nutrients are formed. This leads to variation in vegetation and consequently in organic matter accumulation which is of importance in profile development.

Influence of parent material on soil properties: Parent material determines to a great extent the physical properties of a soil as texture, structure and water holding capacity. The soils developed on sand or sandstone will have deeper and sandy profiles than those developed on granite, alluvium or loess. Different parent materials produce different soils. For example, under humid condition, acid igneous rocks like granite and rhyolite produce light textured podzolic soils (Alfisols); basic igneous rocks (basalt), like limestone or basalt produce fine-textured cracking soils (Vertisols); basic alluvium, or aeolian materials produce fine to coarse textured soils (Entisols or Inceptisols).

The silica sesquioxide ratio in the basic soil is more than two whereas in soils of the tropical regions, the ratio is less than two. The type of parent rock influences soil texture. Siliceous materials like sandstone tend to develop sandy soils while basic rocks and fine grained sediments tend to develop fine-textured soils.

The type of parent material also influences the clay content of soils. Under humid conditions, the parent materials produce soils containing a higher amount of clay. Under arid and semi-arid regions soils with low clay content are formed. This is because of slower decomposition rates under arid and semiarid regions.

Chemical and Mineralogical Composition of Parent Material

The mineralogical, chemical and mineral composition of parent rocks (Tables 4.1, 4.2 and 4.3) leads to the development of different soil groups. For example, Podzol develops on siliceous, Chernozem on calcareous and black soils on basalt parent materials.

RELIEF OR TOPOGRAPHY AS A FACTOR OF SOIL FORMATION

Relief implies relative elevation, i.e. differences of elevation within it. Thus, the inequalities of land elevation are considered collectively. Topography influences local soil patterns. The prominent types of topography designation, as given in FAO guidelines (1990) are:

Land surface	Slopes
Flat to almost flat	0–2%
Gentle undulating	2–5%
Undulating	5–10%
Rolling	10–15%
Filling	15–30% Steeply
Steeply dissected	>30% with moderate range of elevation (<300m)
Mountains	>30, with great range of elevation (>300m)

Important Effects of Topography

Water movement: Relief influences soil development mainly by affecting

Table 4.1. Average mineralogical composition of some important rocks

Rock Containing (primary materials)	Granite	Basalt	Shale	Sand- stone	Lime- stone
Feldspar	52.4	46.2	30.0	11.5	—
Quartz	31.3	—	2.3	68.8	—
Pyroxene-amphibole	—	44.5	—	—	—
Iron oxide minerals	2.0	9.3	10.5	2.0	—
Clay minerals	14.3	—	25.0	6.6	24.0
Carbonates	—	—	5.7	11.1	76.0

water movement. Soils on slopes are generally well drained and well aerated. The effects of dryness are pronounced on slopes facing the sun. On slopy lands, less water filters into the soil. Thus leaching and water movement are affected.

Vegetation: Grasses grow on elevated areas and forest plants flourish well in lower areas.

Soil color: Soil may be thin on slope and thick at the base of a slope. Thus sloped areas are grayish and lower areas are black from accumulation of topsoil and organic matter.

Soil erosion: There are differences in the soil horizon thickness in various topographic positions. Moisture and temperature cause these differences.

Toposequences and catenas: A group of soils which have developed from the same parent material in same climate but under different topographical condition owing to variation in relief and drainage is called soil catena (catena is derived from the Latin word meaning chain).

Soils on the upper drier slopes have less profile differentiation and are less weathered than those on lower slopes, containing greater amount of moisture. The rainwater flows rapidly on steep slopes. Thus less water passes down the parent material on steeper slopes and less of the parent material is decomposed. When slope of the land is more, more basic ions and clay move to the bottom of the land. Hence the bottom land soils are darker in color, heavier in texture, deeper and more alkaline than soils on steeper slopes.

Table 4.2. Chemical composition of some rocks

Rock	Composition (%)											
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	Ti ₂ O	P ₂ O ₅	MnO	H ₂ O
Basalt	53	18	5	2	4	7	4	2	1	<1	<1	2
Granite	76	13	<1	1	<1	<1	3	5	<1	<1	<1	1
Mica	58	19	1	7	2	2	2	4	1	<1	<1	2
Schist												
Lime	1	<0.1	Nil	1	<1	55 ⁺	<0.1	<1	Nil	<0.1	Nil	<0.1
stone												
Slate	57	20	10 [*]	3	3	1	3	3	1	<1	Nil	Nil

^{*} Total Fe calculated as Fe₂O₃; + Co₂ = 43%

Table 4.3. Mineral composition of rocks

Rock	Mineral composition
Basalt	Labradorite, augit, goethite, olivine and opaque
Granite	Quartz, microcline, biolite, oligoclase, muscovite, accessory minerals, apatite and opaque
Mica-schist	Muscovite, biotite, chlorite, granet, quartz, oligoclase, iron ore and apatite
Lime stone (calcite)	Calcium carbonate
Slate	Quartz, chlorite, muscovite, apatite, tourmaline, albite and opaque

TIME AS A FACTOR OF SOIL FORMATION

The time span from the inception of zero point of soil (parent material) development to the present age is termed time. The parent material passes through the following five stages of soil formation when it gradually decomposes to form soil :

Initial stage: The parent material has not yet weathered.

Juvenile stage: Weathering of parent material has just started.

Verile stage: The easily decomposable parent material has just decomposed to form clay, so the percentage of clay in soil has increased.

Senile stage: Slowly decomposable primary minerals have also decomposed

Final stage: Soil profile development is practically complete.

Time and other interrelated factors

The length of time required for a soil to develop depends upon climate, nature of parent material, and relief.

Climate

In the tropics, with high temperature and high humidity, soil formation proceeds much quicker. Extremes of cold and dry climate, low rainfall and low humidity retard soil development.

Parent material

Impermeable and consolidated parent material high in lime retard soil development. Acid sandy loam's lying on gently rolling topography is conducive to rapid profile development. Under favorable conditions, parent material may be transformed into immature soil and organic matter is accumulated in the surface soil. Only A and C-horizons now exist. As time passes, more parent material decomposes to form B-horizon and some clay, sesquioxides, humus have also illuviated in the B-horizon. Thus all the horizons are developed and soil reaches a steady state of dynamic equilibrium. This is called mature soil, where clays from primary minerals are formed continuously. In mature soil, different genetic horizons can be distinguished. The clay content increases with depth of profile,

accumulating at an intermediate depth. In young soils (immature soils), clay content decreases with depth. In such soils, factors of soil formation and pedogenic processes are still operative. The horizons are therefore not well distinguished.

Slope

Steep slopes with poor drainage retard soil development. Besides this certain other factors like high sodium carbonate content, excessive sandy or clay soil, constant accumulation of soil material by deposition, presence of hard layer near the surface of soil retard soil development with passage of time. In cold countries, there are soils formed 20,000 years ago, which are still immature and contain primary minerals of rock still in a fresh state. Therefore, soil age and soil maturity should be considered separately, as they are two different parameters.

CLIMATE AS A FACTOR OF SOIL FORMATION

Climate includes rainfall, temperature and wind. Differential heating causes local variation in the earth's temperature. This leads to air mass movement and induces precipitation. The concept of zonality in soil classification is based on the effect of climate on soil formation (zonal, intrazonal and azonal). Soils that fitted with the climatic zones became known as zonal soils, those where the parent material dominated was called intrazonal, and those where soil formation was restricted were called azonal. Vegetation changes with climate but parent material and relief are relatively constant and soil properties can be related to climate.

Rainfall

Rainfall affects leaching, climatic water balance, profile development and presence of calcium carbonate layer.

Leaching: Leaching causes accumulation of materials like clay and plant nutrients in the lower parts of the soil. Excess rainfall leaches silica and basic materials down the soil profile due to intense weathering and makes soil acidic in reaction. The acidic conditions favour the formation of hydrogen oxides of iron and aluminium. The nature, distribution and amount of rainfall determine the movement and depth of deposition of soil colloids. Crowther has considered a leaching factor on the basis that to maintain a constant leaching, a rise of, 1°C in temperature must be accompanied by an increase of 3.3 cm in rainfall.

Climate water balance: Climatic water balance is the difference between gain in water mainly through rainfall and loss of water due to evaporation. Climatic water balance may be estimated by various means:

$$\text{i) Lang's Rain Factor} = \frac{\text{Mean annual rainfall in mm}}{\text{Mean annual temperature in } ^\circ\text{C}}$$

$$\text{ii) Niederschlag Sathigungs deficit Quotient (NSQ of Meyer (1962))} \\ \text{NSQ} = \frac{\text{Rainfall in millimeter}}{\text{Absolute saturation deficit of air mm of mercury}}$$

$$\text{iii) Thornthwaite's (1931) Precipitation Effectiveness Index (PE index)} \\ n=12$$

P.E. index

 Σ

115

$$\left[\frac{P}{T-10} \right]^{10/9}$$

n=1

Where P= Monthly rainfall in inches

T= Mean monthly temperature in degree F

n= Concerned month

The climatic water balance influences the amount of water reaching on the surface of the earth. As this amount of water increases, decomposition of primary mineral increases and thus clay content increases. Also, more plentiful is the vegetation, and more is the accumulation of organic matter.

Profile development: Rainfall also affects profile development through erosion, producing thin soils on slopes and deposition of soil material in low-lying areas. A soil is said to be developed when it has detectable layers (horizons) such as accumulated clays, soluble salts, carbonates that moved downward by water.

Presence of calcium carbonate layer near the surface of soils in arid regions: Calcium carbonate is not leached if sufficient water is not present.

Temperature

Speed of chemical reactions

Temperature affects the speed of chemical reactions. The higher the temperature the faster a reaction, The rate of any chemical reaction is doubled for each 10°C rise of temperature. Thus, in tropics, soils develop more rapidly. In cold areas, like the tundra, soils develop slowly.

Decay of organic matter

Warm temperature also speeds up the decay and loss of organic matter. Thus soils of warm climate tend to be low in organic matter. The organic matter content in soil is nearly doubled for every 10°C lowering of temperature. In general, with increasing temperature, the depth of weathering and clay content show an increase.

Soil colour

Reddish soils are predominant in the tropics because of intense hydration and oxidation of iron and other compounds whereas grayish soils occur in the temperate regions. In arid regions soils are relatively shallow because the water does not penetrate very deep. They are light coloured because little organic matter accumulates under the sparse vegetation. The soils are neutral or even alkaline in reaction because the soluble salts are not thoroughly leached from such soils.

Wind

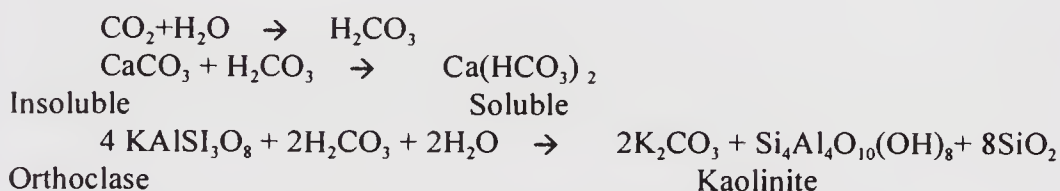
Wind transports large quantities of fine particles and deposits them over wide areas as sand, loess etc. The soil receives through wind transport considerable quantities of various salts. The salts in the atmosphere originate from volcanoes and electrical discharges.

BIOSPHERE AS A FACTOR OF SOIL FORMATION

Biosphere comprises all plant, man and microbiological life. These organisms improve soil productivity by decomposing rocks, minerals and organic matter.

Plants

Effect of lichens, mosses and algae : Plants contribute to soil formation by helping to break down the rock. Lichens, mosses and algae grow on bare rocks and respire to produce carbon-dioxide, that react with water to form carbonic acid, which dissolves primary minerals and release the nutrients for plant growth. Algae uses atmospheric nitrogen, which is released in the soil upon the death of the algae.



Addition of organic matter (effect of grasses): Plants add organic matter to the soil. Grasses, litter and plant residues create a surface layer of organic matter. Root density of grasses declines with depth. Many roots die to produce a significant amount of organic matter. Grasses are very effective at offsetting leaching by recycling soluble materials. Recycling occurs when ions are absorbed by roots and translocated up through the plant. Recycling process is especially significant for cations such as Ca, Mg, Na, K that are gradually leached from the soil.

Effect of forests: The horizon developed under forests is acid. The compounds of iron and aluminium are more soluble and leach faster under acid conditions. The B-horizon of such soils may therefore have illuvial deposits of organic matter and Fe and Al compounds in addition to clay deposits.

Type of vegetation: Plants differ in their nutrient revival to soil. For example, the pines favor podzol formation because of low bases and their leaches are acidic. Deciduous trees bring up lime and produce brown earth.

Soil protection: Plants act as a vegetative cover and reduce normal erosion rates. Thus vegetation acts as an agent of soil protection against the forces of disintegration.

Animals

Macroorganisms: Burrowing animals, earthworms, beetles, rodents, moles, centipedes, termites dig up the soil, mix up the material and disturb the soil profile. They interrupt soil development and tend to retard horizonation.

Earthworm: The organic and mineral matter is grinded and adds digestive juices. Their excretions are rich in calcium and granular in structure.

Crotovinas are abandoned pathways of rodents or earthworms filled with soil and cover about 30% of the soil matrix. Wormiculture, i.e. the raising of earthworm on the farmlands and the use of their casts as manure is being encouraged.

Micro-organisms: It includes microflora and microfauna.

Microflora: Bacteria, actinomycetes, fungi and algae

Microfauna: Protozoa and nematodes

Micro-organisms help soil development by slowly decomposing organic matter and forming weak acids. Weak acids dissolve minerals faster than water. Soil supports billions of bacteria and other micro-organisms. Micro-organisms like bacteria and fungi are responsible for processes like nitrification, sulfur oxidation. They act on mineral content of rocks. These micro-organisms usually survive best under aerobic conditions, and a temperature between 25°-30° C is optimum. These conditions are met in tropical and subtropical regions. Soil acidity (pH 3.5 to 5.5) is favorable for fungi, and pH between 6.5 to 7.5 is best for bacteria. Actinomycetes thrive well in slightly alkaline condition.

Man

Man contributes in soil formation through cultivation practices. However, deforestation, overgrazing and degradation of land have increased erosion and influences soil forming processes.

References and Suggested Readings

- Barshed, I. (1955). Soil development. (In). *Chemistry of the Soil*, Bear, F.E. (Ed.). New York (Reinhold).
- Brady, N.C. (1995). *The Nature and Properties of Soils*. Prentice Hall of India Pvt. Ltd., New Delhi.
- Fitzpatrick, E.A. (1983). *Soils, their Formation and Distribution*. Longman, London and New York.
- Plaster, E.J. (1992). *Soil Science and Management*. Delmar Publishers, New York.

QUESTIONS

Q. 1. Fill in the blanks

- (i) Any soil property, is a function of the collective effects of all _____.
- (ii) In general, the rate of any chemical reaction is doubled for each _____ rise of temperature.
- (iii) Because of intense hydration and oxidation of iron and other compounds color of soils in the tropics is likely to be _____.
- (iv) In high rainfall regions, the clay content _____ with depth.
- (v) Acidic conditions developed due to leaching of bases favour formation of _____ clay minerals.
- (vi) Retention of bases favour formation of _____ and _____ type of clay minerals.

Answers

(i) soil forming factors (ii) 10°C (iii) reddish (iv) increase (v) kaolinitic (vi) illite and montmorillonite.

Q. 2. Choose the correct answer

- (i) Quartz rich rocks like granites and sandstone yield more sandy material/

clayey material.

- (ii) Iron and manganese impart red/ black color to soils.

Answers

- (i) sandy material (ii) red

Q. 3. Define the following

- (i) Weathering (ii) Relief

Q. 4. Differentiate between factors of

- (i) Active and Passive factors of soil formation
(ii) Mature and Immature soil
(iii) Endodynamorphic and Ectodynamorphic soils

Q. 5. Write short notes on

- (i) Toposequences and catena
(ii) Profile development

Q. 6. Comment on the following statements

- (i) Soil formation is the result of interaction of soil forming factors
(ii) The soils of warm climates tend to be low in organic matter
(iii) Parent material generates different type of soils
(iv) Sloped areas are grayish and lower areas are black
(v) If erosion is heavy, mature soils may not develop

Q. 7. Answer the following in brief

- (i) What two distinct processes comprise soil formation
(ii) What is meant by a 'developed' soil
(iii) How does plant influence soil formation
(iv) Enlist five stages in the formation of soil from parent material

Q. 8. Answer the following in detail

- (i) Explain the process of formation of soil profile with time.



5

Soil Profile Development and Processes in Pedogenesis

PHYSICAL and chemical weathering of rocks leads to the formation of parent material, the original material from which the soil forms. Pedogenic processes then act upon parent material. These processes include i). Decomposition ii). Synthesis iii). Illuviation iv). Eluviation v). Accumulation and vi). Homogenization.

Decomposition

Decomposition of rocks and minerals occurs by solution, oxidation, hydrolysis, carbonation, hydration and reduction. Thus,

- (i) Silica, alumina and iron oxides are converted into their hydrated forms
- (ii) Soluble salts of Ca, Mg, K, Na, Cl, SO_4 , HCO_3 and CO_3 pass into solution
- (iii) Decomposition of organic matter adds humus, NH_3 , NO_3 , SO_4 and PO_4 ions.

Synthesis

Decomposed soil materials are synthesized into new compounds. It includes formation of clay minerals, humus, hydrated oxides of Fe and Al, carbonates of Mg, Ca, K, Na and oxides of Mn, Ti etc. The nature and quantity of the different compounds synthesized will depend on rainfall, temperature, concentration of ions in solution and pH etc.

Illuviation

By illuviation is meant the deposition of dissolved material in some parts of the soil mass. Dissolved materials move downward, upward and laterally with drainage water. The concentration of colloidal material in different layers (at varying depths) depends on the extent of leaching. Under restricted leaching, calcium precipitates as CaCO_3 , or CaSO_4 . Under heavier leaching colloidal organic matter gets precipitated by Al ions.

Eluviation

Eluviation is the removal of constituents for example clay, organic materials and silica. Silica is removed under humid tropical conditions as in laterite soils. Illuviation and eluviation have been described separately under fundamental soil forming processes.

Accumulation

Accumulation of organic matter is common during early stages. Under certain

weathering conditions, one mineral may be transformed into another and accumulate for example formation and accumulation of kaolinite clay from feldspar. Translocation and accumulation of material can also be a cause of horizon formation. For example, in laterites and red soils, the concentration of oxides of Fe and Al are increased due to leaching away of silica, lime and other elements.

Homogenization

Processes like decomposition, synthesis, eluviation, illuviation, and accumulation result in the development of layers or horizons in the soil body. Cultivation practices and activity of soil organisms tend to churn up the soil and disrupt the formation of horizons. This leads to an overall effect causing homogenization of soil material.

From the above discussion, it is concluded that there are no distinct stages in the development of soils. However, it may be said that significant changes take place in the parent material to form soil. The properties of soil so formed are determined by two kinds of characteristics, i.e. inherited and acquired.

INHERITED AND ACQUIRED SOIL CHARACTERISTICS

Inherited characteristics are derived from parent material and hence they are geological in nature. For example, presence of primary minerals like quartz and feldspars that remain unaltered into the soil. Colour is often inherited as in sandstone (red) or shales of various colours. In the early stages of soil formation, i.e. in young soils, inherited soil properties are dominant.

Acquired characteristics are more local in nature. For example, presence of organic matter, clay formation and soil characteristics developed due to processes like eluviation and illuviation. Acquired soil characteristics become more prominent as the soil develops, i.e. in the older soils.

THE SOIL PROFILE

As the soil develops horizontal layers (horizons) form in the soil. The description of a soil profile consists of description of its several layers (horizons). A soil horizon may be defined as a layer of soil, parallel to the soil surface, with characteristics produced by soil forming processes. The horizons are visible wherever the earth is dug deep enough to expose them. The soil profile is a vertical section through the soil, extending well into the unweathered parent material and exposing all the horizons. Every soil profile has its own distinctive characteristics, i.e. no two soil profiles are exactly alike.

Soil monoliths

These are permanent records of important soil profiles. Thus undisturbed soil profile columns are preserved in wooden or metal boxes. Wooden boxes are prepared by pasting on hard board or by putting in small wooden boxes (3"×1.5"×12") proportionate undisturbed sections of each horizon. Gluing materials like vinyl resin are used to preserve the monoliths in natural condition.

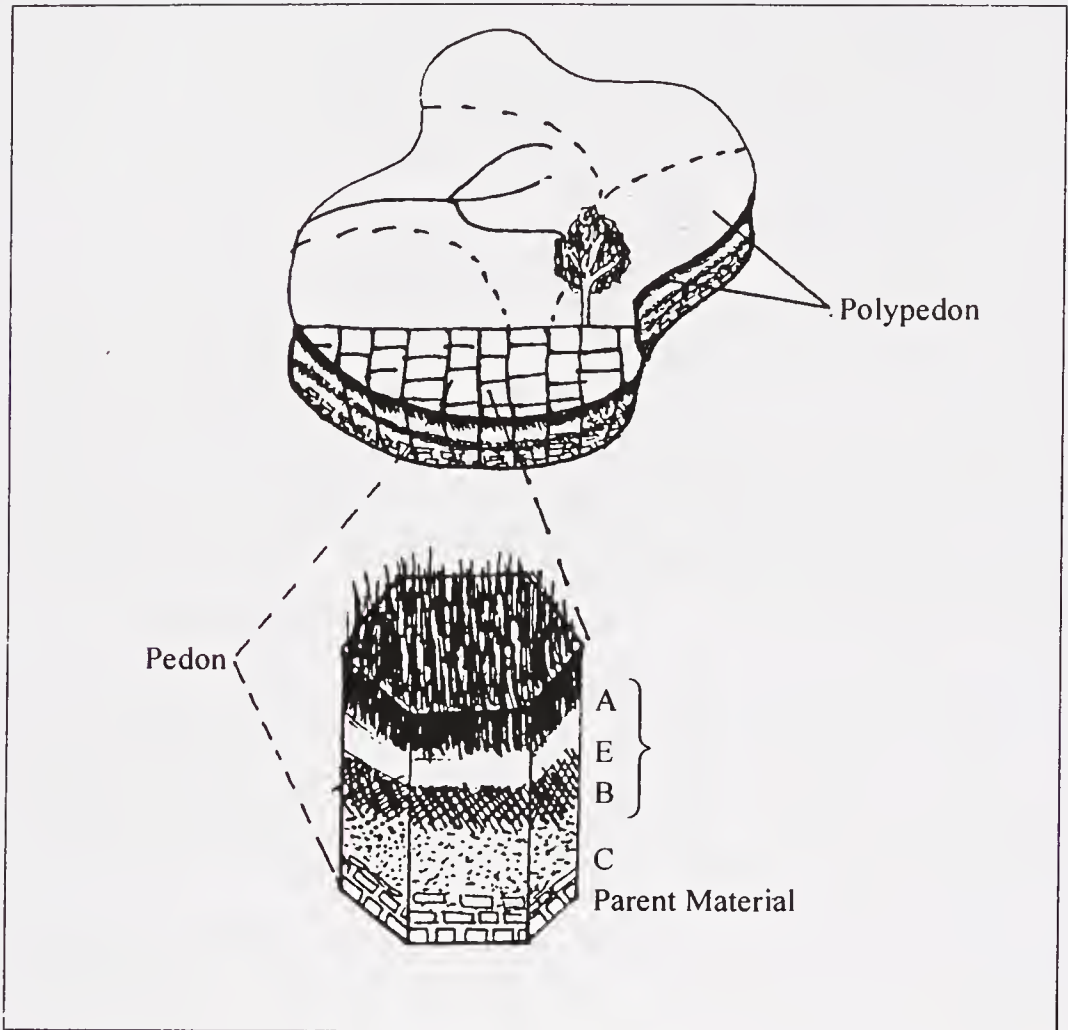


Fig. 5.1. A typical soil pedon

PEDON

A soil profile is studied from a freshly exposed pit through small soil body. To study a whole body of soil, soil is broken up into smaller parts that can be easily studied, i.e. minimum soil volume must be chosen that will represent an individual soil. Such a minimum volume is called a pedon (Fig. 5.1). It has the smallest area of the sample to be taken to represent the nature and arrangement of horizons. A pedon is the three-dimensional soil unit defined to have all the characteristics of a soil. The area of a pedon ranges from 1 to 10m² depending on the variability of soil. In general a pedon covers an area of 1m² except those circumstances where it must be larger to fully represent the soil. Thus the concept of pedon includes the vertical and lateral extent of soil. The concept of profile includes the vertical extent of soil. The term polypedon is used to designate a soil area composed of many similar pedons that are all given the same soil name.

In a very young soil, there is a thin layer of soil called A horizon, which is a surface mineral horizon with organic matter accumulation. The parent material below the A horizon of this young soil is termed as the C horizon which is a sub

surface mineral layer only slightly affected by soil forming processes. Thus the young soil has an AC profile. Later, the soil materials including clays and chemicals leach out of the horizon moving, downward in the profile to create a new layer, B horizon. Thus a mature soil develops.

SURFACE SOIL AND SUB SOIL

Surface Soil

- i) The surface soil (0-15 cm depth) is subjected to various cultivation practices.
- ii) It is the major zone of root development, darker in color due to organic matter, subjected to tillage operations and activity of soil organisms.
- iii) It is completely weathered, loose and friable.
- iv) Surface soil has more number of micro-organisms and higher organic matter and nitrogen content.

Sub Soil

- i) The subsoil (below 15-cm depth) is more compact and lighter in colour. It is subjected to little alteration except by drainage.
- ii) Formation of hard pan due to accumulation of clay and calcium carbonate in subsoil adversely affects crop production.
- iii) Sub soil is raw weathered, compact and has poor aeration.
- iv) It has lower organic matter, nitrogen and is less fertile than surface soil.

MASTER HORIZONS

A theoretical soil profile

The soil horizons indicate the history of soil formation and are the results of soil forming processes. Five master horizons are recognized and they are designated as O A E B C. Below them is the bed rock which may be designated as R. Thus a theoretical soil profile consists of the following:

Horizon	Soil characteristics
O	An organic layer developed from wholly or partially decayed plant and animal residues. It is subdivided as follows:
Oi	Consists of slightly decomposed plant material, the original form of which can be recognized
Oe	Consists of incompletely decomposed plant material.
Oa	Consists of completely decomposed plant material, the original form of which cannot be recognized. [O horizon usually occurs in forest regions].
A	Topmost mineral horizon, clay humus complex, dark colored
E	Horizon of eluviation, light in color.
B	Zone of accumulation (illuviation) of clay, sesquioxides, humus
C	Parent material that is partially or fully weathered material from which AE and B-horizons have developed. Its upper layer in time may become part of the solum as weathering and erosion continues.
R	Underlying rock.

Transition horizons

Horizons between the master horizons dominated by the properties of one but also have characteristics of the other as well. Both capital letters are used to designate the transition horizons for example AE, EB etc. The dominant horizon is listed first, i.e. in AE the characteristics of A horizon are dominant over E horizon. Also, A/E are used to designate transition horizons where in a layer (horizon) distinct parts of the horizon have properties of A and only minor parts have properties of B.

Other symbols used to characterize horizons

Ah	High organic matter content
Ap	Mixed by plowing
Aq	Gleyed due to waterlogging
By	Accumulation of gypsum
Bz	Accumulation of salts
Bg	Partially gleyed; blocky or prismatic structure, MnO_2 mottles
Bh	Translocated organic matter with Fe and Al
Bs	Enriched with sesquioxides;
Bt	Translocated clay; clay coating low ped faces
Bw	Alteration of parent material by leaching, weathering and structural reorganisation
Ck	Accumulation of secondary CaCO_3
Cy	Accumulation of CaSO_4
Cm	Cemented, other than iron pan
Cr	Weak consolidation but dense enough to prevent root penetration
Cx	Fragipan characteristics; firm when dry and brittle when moist

*Source *: soil survey staff (1981)

Solum is the true soil. It includes A E and B-horizons. Regolith, is the unconsolidated material lying above the bed rock. It includes A E B and C horizon. Usually all the above mentioned horizons are not found in every soil profile because they may be immature (not well developed). A few typical soil profiles are presented in Fig. 5.2

SOIL MORPHOLOGY

A study of horizons in a soil profile, their sequence, depth and characteristics is known as soil morphology. It gives a picture of the inherent characteristics of soils acquired during their evolution. The morphological features are the mirror images of the processes responsible for its development. The differences in parent rock, climate, vegetation and intensity of pedogenic processes have their impression in the profile. This comprises description of individual soil profiles in respect of:

- General information of the site and soil.



A. Paralithic Ustropept



B. Typic Ustropept



C. Rhodic Haplustalf



D. A typical profile of Vertisol (Chromustert) showing slickensides and wedge-shaped structure

Fig. 5.2. Some Typical Soil Profiles

- Description of individual soil horizons including description of soil color, texture, structure, consistency, depth and thickness, sharpness of boundaries and physico-chemical and chemical characteristics like pH, plant nutrients, organic matter, lime, salt content, nature of clay, sesquioxides etc.
- Root penetrations, concretions, incrustation and new formations in each horizon.
- Miscellaneous observations like topography, natural vegetation, parent rock, local meteorological conditions.

PROCESSES IN PEDOGENESIS – FUNDAMENTAL VERSUS SPECIFIC SOIL FORMING PROCESSES

The simultaneous interaction of soil forming factors under a particular set of conditions which develop specific profile features, form soil forming processes. Unlike soil forming factors which usually act collectively, process may occur separately or simultaneously. Soil forming processes are of two types, i.e. fundamental and specific. Pedogenic processes change parent material to soil and work faster than geological processes (weathering). Though all the five genetic factors contribute to the development of each soil, all pedogenic processes influence no single soil.

Fundamental processes involved in soil formation are addition, losses, and transformation of organic and mineral matter. All these processes promote horizon differentiation. Specific processes bring about certain specific features by means of a variety of reactions. Important fundamental and specific soil forming processes and reactions are listed in table below:

Fundamental processes	Specific processes	Soil reaction
Humification	Podsolization	Oxidation, Reduction
Eluviation	Calcification	Carbonation, Hydration
	Decalcification	
	Laterization	
Illuviation	Salinization	Mineralization,
	Desalinization	Immobilization
Horizonation	Alkalization	Ammonification,
		Nitrification
	Gleization	Precipitation,
		Solubilization
	Pedoturbation	Decomposition,
		Translocation

FUNDAMENTAL SOIL FORMING PROCESSES AND THEIR CHARACTERISTICS

Humification

The processes involved in the decomposition of organic matter (material of

plant or animal origin) leading to the formation of humus is called humification. It helps in the formation of the surface humus layer (Ao horizon). Humic substances may get dissolved and pass in lower layers through percolating water. In tropical and subtropical regions, they may not accumulate because of intense microbiological activity. Micro-organisms control biological oxidation of organic matter whereas under anaerobic conditions there is an increase in soil pH causing reduction in iron and manganese to form Fe^{2+} and Mn^{3+} , denitrification resulting in loss of free nitrogen.

Eluviation

Eluviation is the process of removal of constituents, that is mobilization and translocation of clay, iron and aluminium oxides, humus, CaCO_3 and other salts from the upper layer to lower layers by percolating water. Thus layer formed due to loss of soil constituents is called eluvial layer or horizon (meaning-washed out). This results in the formation of horizons. Silica is removed under humid tropical condition as in the laterite soils. During this process, water stability of peds is reduced and dispersion of clay starts.

Illuviation

Deposition of materials transported from a higher soil layer in the lower layers by percolating water is called illuviation. The layer formed due to deposition is called illuvial layer or horizon (meaning-washed in). The colloidal clay and humus hold cations and anions by adsorption. These substances in solution are deposited in lower layers. Similarly deposition of clay, aluminium and iron oxide takes place in lower layers.

SPECIFIC SOIL FORMING PROCESSES AND THEIR CHARACTERISTICS

Podsolization

Podsolization is the process of removal of oxides of iron and aluminium, humus, carbonates by organic acids and their deposition in lower horizons. The conditions necessary for podzol formation are:

i) A humid climate ii) An acid soil ii) Acid humus producing vegetation.

Therefore, podsolization occurs to a great extent in forests. It involves excessive leaching and takes place in cool humid climates with high rainfall. The parent material is acidic which results in the formation of acidic soils. The processes of podsolization occurs as follows:

- The weathering of acidic parent material results in the formation of acidic soils.
- Plants which grow on these soils release organic matter to soil poor in bases and decomposes to produce organic acids.
- Organic acid decomposes clay to liberate silica, alumina, and iron and becomes grey in color.
- Iron and aluminium ions then move to the B_2 horizon. These positively

charged iron and aluminum ions react with negatively charged clay and humus, which results in their precipitation.

A typical podzol profile consists of three horizons:

- The A₁ or eluviated horizon consists of peat
- The A₂ horizon is drastically leached and assumes a leached grey appearance because of the grey color and ashy appearances of the A₂ horizon (in Russian Pod means 'under' and zola means 'ash'). Such soils are called podzols.
- The B-horizon consists of precipitated humus and sesquioxides.

Laterization

The term laterite is derived from the word 'later' meaning brick. It refers to a particular cemented horizon in certain soils which, when dried becomes very hard like a brick. When such soils contain sesquioxides (iron and aluminium oxides) are called laterites. Laterization is the process of removal of silica and accumulation of sesquioxides. High temperature and high rainfall are essential for their development. Thus, weathering processes work much faster in tropics and semitropical regions. Hydration and oxidation are intense and as a result of this, silicate minerals are quickly affected. The regolith becomes deep due to intense weathering. The process of laterization occurs as follows:

- The basic parent material rich in ferromagnesian minerals is congenial for the development of laterites.
- The ferromagnesian minerals and organic matter decompose to release silicon, aluminium, iron and basic cations. The basic ions make the medium alkaline, keeping silicon ion in solution. Thus silica is washed down by high rainfall. Iron is precipitated and oxidized to ferric oxide (red in color).
- When basic materials are washed down, kaolinite (1:1) clay minerals form, which later decompose to hydrous oxides of iron and aluminium.

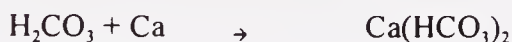
Calcification

It is the process of precipitation and accumulation of calcium carbonate in soil profile. This may be explained as follows:

- When CO₂ concentration is high in the root zone, carbonic acids are formed



- Calcium is readily soluble in carbonic acid

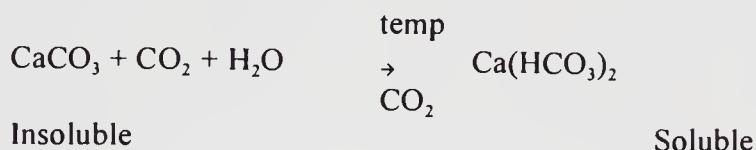


- $\text{Ca}(\text{HCO}_3)_2 \xrightarrow{\text{temp}} \text{CaCO}_3 + \text{H}_2\text{O} + \text{CO}_2$
Soluble $\xrightarrow{\text{CO}_2}$ precipitates

Under restricted leaching as in arid and semiarid climate, calcium ions precipitate and deposited as a hard layer of calcium carbonate. Parent material in these regions are also rich in lime. Low rainfall is unable to move then

downwards. The vegetation, particularly grasses are important in the process of calcification. Grasses have extensive root system, which provides sufficient organic material. Organic material stabilizes the soil colloids in presence of calcium thereby preventing downward movement of finer fractions.

Decalcification, is the process of removal of CaCO_3 from the soil by leaching.

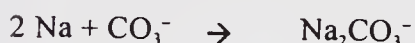
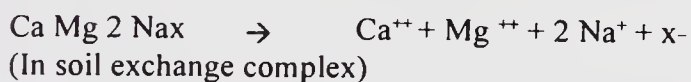


Salinization

Salinization is the process of accumulation of white crust of soluble salts of sulfates and chlorides of calcium, magnesium, sodium and potassium. These soils are formed because of these salts which originate from the decomposition of primary minerals in the soils of arid regions. Arid and semiarid climate conditions, associated with shallow and brackish ground water, lower topographic position, poor drainage of salts and saline irrigation waters are other important condition where such soils develop.

Alkalization

The process of accumulation of sodium on this exchange complex of soil resulting in the formation of alkali soils. It can be represented as:



Since solubility of Na_2CO_3 is 1000 times more as compared to Ca or Mg carbonates. Thus Na^+ concentration is high in soil solution and it gets adsorbed on exchange sites of clay and organic matter. Calcium ions in soil are replaced by sodium ions. The color becomes black due to dissolution of organic matter under alkaline conditions. This forms black organic-clay coatings on soil surfaces. This results in deflocculation and destruction of normal structure of the soil. Such soils have columnar or prismatic structures.

Gleization

The term 'glei' is of Russian origin, which means blue, grey or green clay. Thus a glei layer, which is compact and contains higher concentration of Ca, Mg, Fe and Mn salts because of their increased solubility, develops due to following reasons:

- When soil parent material is impervious to water
- Depression land, where water stands continuously
- Poor aeration

Under such conditions ferric iron is reduced to ferrous iron which are bluish

grey in color. Such waterlogged horizons are termed 'glei' and the process by which they are formed is known as gleization.

Pedoturbation

Soil forming processes cause horizon differentiation or vertical differences in the chemical and mineralogical composition of the soil. In contrast to this, other processes operate which tend to make the soil more uniform vertically. Intermixing of soil horizon due to soil forming processes take place continuously. This process of mixing in the soil body has been termed pedoturbation. Pedoturbation is an attainment of equilibrium between change within the soil material and the external environment. The common types of pedoturbation are:

- Faunal pedoturbation (mixing of soil by animals)
- Floral pedoturbation (mixing of soil by plants)
- Argilli pedoturbation (mixing of material by shrinking and swelling of clays).

References and Suggested Readings

- Arakeri, H.R. and Donahue, R.L. (1985). *Principles of Soil and Water Conservation and Water Management*. Oxford and IBH Publishing Co., New Delhi.
- Flint, F.R. and Skinner, B.J. (1977). *Physical Geology*, 2nd edn. Wiley and Sons, New York.
- Jenny, H. (1941). *Factors of Soil Formation*. Mc-Graw Hill Book Co. Inc, London and New York.
- Pitty, A.F. (1979). *Geography and Soil Properties*. Methnen, London.
- Sehgal, J (1996). *Pedology Concepts and Applications*. Kalyani Publishers, Ludhiana.

QUESTIONS

Q. 1. Fill in the blanks

- (i) Deposition of materials transported from a higher soil layer by percolating water is called _____.
- (ii) _____ is the process of removal of silica and accumulation of sesquioxides.
- (iii) Formation of glei layer is a characteristic of process called _____.
- (iv) _____ is an attainment of equilibrium between change within the soil material and the external environment.
- (v) The original material from which soil develops is called _____.

Answers

- (i) illuviation (ii) laterization (iii) gleization (iv) pedoturbation (v) parent material

Q. 2. Choose the correct answer

- (i) In the early stage of soil formation inherited/ acquired soil characteristics are dominant.
- (ii) Solum/Regolith is the true soil.
- (iii) Podolization/Laterization commonly occurs in forests.
- (iv) Swelling of clays is argillipedoturbation/floral pedoturbation.

Answers

- (i) inherited (ii) solum (iii) podolization (iv) argillipedoturbation

Q. 3. Define the following

- (i) Humification (ii) Eluviation (iii) Soil profile (iv) Horizon

Q. 4 Differentiate between

- (i) Soil forming processes and soil forming factors (ii) Fundamental and Specific soil forming processes (iii) Salinization and Alkalization (iv) Inherited and Acquired soil characteristics (v) Surface soil and Sub soil.

Q. 5. Write short notes on

- (i) Podsolization (ii) Calcification (iii) Salinization (iv) Pedoturbation (v) Soil monolith (vi) Pedon (vi) Soil morphology (vii) Gleization

Q. 6. Comment on the following statements

- (i) Podsolization occurs to a great extent in forests
(ii) Laterization favours formation of kaolinite clay minerals and hydrous oxides of iron and aluminium

Q. 7. Answer the following in brief

- (i) What is meant by soil forming processes
(ii) Enlist fundamental soil forming processes
(iii) Enlist specific soil forming processes

Q. 8. Answer the following in detail

- (i) What are the typical characteristics of a podzol profile
(ii) What are master horizons. Explain their characteristics.

Q. 9. Give diagrammatic view of the following

- (i) A hypothetical soil profile



6

Soil Classification

SEVERAL systems of soil classification have been proposed before the present internationally adopted system of soil classification called soil taxonomy came in force. It is worthwhile to briefly review the old systems of classification for a better understanding of the need and importance of soil taxonomy. This requires grouping soils with similar properties so that lands can be efficiently managed for crop production. In order to understand the differences, similarities and relationships it is necessary that soils be grouped in an orderly manner.

The soil individuals are grouped into classes of lower category, which are further grouped into classes of higher categories. The lower categories are comprised of a large number of differentiating characteristics and higher categories by means of a few differentiating characteristics. The various system of soil classification can be summarized as :

EARLY SYSTEM OF SOIL CLASSIFICATION

Economic classification: One of the earliest system of soil classification adopted by the revenue department for grouping soils according to their productivity for the purpose of taxation. This was based on the productivity of the land evidence by yield per unit area. The criteria used were soil color, texture and irrigation potentialities. This is not scientific since crop yield is the interactive effect of soil and environmental factors.

Physical classification: It is one of the earliest systems and was based on soil texture, a property associated with soil productivity. With the development of scientific studies other soil properties like pH, CaCO_3 , salts and availability of plant nutrients were also included.

Chemical classification: This is based on the grouping of soils on the basis of their chemical composition. Data on chemical composition of soil cannot be classified according to any definite pattern.

Geological classification: This is based on the fact that soil is the product of decomposition of rocks. Effect of climate on the soils is well defined where climate remains uniform for most part of the season. However, under extreme climatic conditions of temperature and precipitation, the effect of parent materiel is minimal. For example, in arid and semiarid tropics, the effect of geology is less evident. Thus, climate overcomes the influence of parent material over a period of time.

According to this system, two broad groups of soils are recognized.

Residual or sedentary soils: Developed *in situ* from the underlying rocks like basalt, limestone or sandstone.

Transported soils: Soils developed on unconsolidated sediments like alluvium, colluvium or aeolian materials.

Knowledge of the geology of the parent material is of great value in explaining many properties of a soil.

Classification based on factors and processes of soil formation: This is based on the principle that different kinds of soils formed are the results of combinations of different soil forming factors and processes.

Factors of soil formation: Broad divisions of soils based on the dominant factors of soil formation are as follows:

Thermogenic: High temperature is the dominant factor, which causes mineralization of soil residues and decomposition of silicate mineral.

Phytogenic: Humid conditions favor accumulation of organic matter as in podzols.

Hydrogenic: Water is the dominant factor of soil formation.

Halogenic: Soils with dominance of sodium salts and includes saline and alkaline soils.

Processes of soil formation: Soil forming processes like eluviation and illuviation and synthesis of new compounds which results in the formation of developed and undeveloped soils.

The collective influence of factors of soil formation as reflected in the soil profile.

These systems of classification could distinguish only broad categories of soils. Thus they could not be adopted on a large scale.

Climatogenic classification: The soil profile reflects the origin and mode of formation, i.e. the genesis of the soil. Climate and vegetation may be regarded as a single variable and based on them a classification of genetic soil types can be drawn. Decomposition of humus is a biochemical reaction and its speed is increased by temperature. Increasing humidity leads to percolation and has greater leaching. These facts explain the characteristics of different soil types formed under the influence of climate and vegetation.

Coffey's system of soil classification: Coffey (1912) emphasized that soils should be classified on the basis of their properties. He proposed five major classes of soils as under :

(i) Arid soils (ii) Dark - coloured prairie soils (iii) Light – coloured timbered soils (iv) Black swamp soils (v) Organic soils

Each class was subdivided into series on the basis of parent material and the series into types on the basis of surface soil texture.

The American classification: Marbut defined soils on the basis of their characteristics and established that soil character varies according to the interaction of all soil forming factors. Marbut (1935) proposed that soils can be divided into two groups, pedocals and pedalfers. The differentiating criterion was the presence or absence of a layer of calcium carbonate at the base of the solum.

Pedocals: Layer of CaCO_3 formed under dry climate where evaporation is high.

Pedalfers: Show accumulation of iron and aluminum. Absence of a layer of CaCO_3 indicates humid climate.

Marbut emphasized that soil classification should be based on soil morphology and stressed the need for examination of actual soils for their characteristics. The major limitation of this system was that, it was based, in part, on assumptions concerning soil genesis.

Marbut's morphogenetic soil classification system was revised and elaborated by Baldwin, Kellogg and Thorp (1938). Based on this classification soils have been classified into zonal, intrazonal and azonal.

Zonal soils: Climate and vegetation govern the characteristics of these soils. The soils developed from different parent material under the same climate and vegetation have same general characteristics. They have well-developed profiles. The soils are termed as zonal because the development of their profiles closely corresponds to the climatic and vegetation zones in which they occur.

Intrazonal soils: Soil characteristics are determined by local conditions like poor drainage, soluble salts etc. The influence of climate and vegetation is dominated by local conditions.

Azonal soils: These soils are without a well-developed profile. They include young soils without horizon differentiation. This is because such soils are immature due to parent material or local conditions such as slope. The soils developed on recently laid alluvium or colluvium belong to this group.

Limitations in the genetic system of classification

- All the categories are not defined on the basis of properties of soils themselves. Thus the concepts and definitions of the highest category i.e. the order, in terms of soil properties are not clear.
- The great soil groups are based on environmental factors rather than on soil properties.
- The difference in the properties of soil under virgin conditions (as defined in their classification) and under cultivation may be different and as such classification of such soils becomes ambiguous.
- Definitions of units in lower categories may be more important for one interpretation. Thus it becomes impossible to use these results for other interpretations.

SOIL TAXONOMY

Genetic system of soil classification is based entirely on soil genesis. Soil properties change after years of cultivation and influence of environmental factors. Thus classifying soils on the basis of properties presumed to be possessed by them under natural vegetation will not present a true picture.

The weaknesses of the older system were overcome by present system of classification. This was called soil classification a comprehensive system - 7th Approximation published by soils survey staff in 1960. 7th approximation - it was called so because it was approximated seven times (under the chairmanship of G.D. Smith since 1951). The usage increased with each succeeding approximation. Soil survey staff of United States Department of Agriculture proposed a classification called Soil Taxonomy in 1975. Taxonomy is grouping of objects at

Table 6.1. Genetic system of soil classification

Order	Suborder	Great Groups	Corresponding classes in soil Taxonomy
Zonal soils	1. Soils of cold zone	Tundra soils	Cryaquepts
	2. Light colored soils of arid regions	Sierozem	Argids, Orthids,
		Brown soils	Argids, Ustolls (a few)
		Reddish brown	Argids, Ustolls (a few)
		Desert soils	Orthids, Argids
		Red desert soils	Argids, Orthids,
	3. Dark colored soils of the semi-arid, sub-humid and humid grasslands	Chestnut soils	Ustolls, Borolls
		Reddish chestnut soils	Ustolls (a few)
		Chernozem soils	Borolls, Ustolls
		Prairie soils	Ustolls,
	4. Soils of the forest grassland transition	Reddish prairie soils	Ustolls,
		Degraded chernozems	Boralfs, Borolls
5. Light coloured Podzolised soils of the Timbered regions	Noncalcic Brown soils	Xeralfs	
	Podzol soils	Orthods	
6. Lateritic soils of forested warm temperature and tropical regions	Gray wooded		
	Podzolic soils, Brown podzolic soils		
Intrazonal	1. Halomorphic(saline and alkali) soils of imperfectly drained arid regions and littoral deposits	Reddish brown Lateritic soils	Udults,
		Yellowish brown	Udults,
		Lateritic soils	Some oxisols
	2. Hydromorphic soils of marshes, swamps seepareas and flats	Leterite soils	
		Solonchak or saline soils	Salorthids
		Solonetz soils	Natr great groups
		Soloth soils	Natr great groups
		Humic gley soils	Aqu suborders
		Alpine madow soils	Aqu suborders
		Bog and half-bog soils	Aqu suborders
		Low humid gley soils	Aqu suborders
		Planosols	Albolls, Albaqualfs
Ground water podzols		Aquods	
3. Calcimorphic soils	Ground water laterites	Plinthaquex, Plinthaquults	
	Brown forest soils	Eutrochrepts	
Azonal	No suborder	Rendzina soils	Rendolls
		Lithosols	Lithic orthents
		Alluvial soils	Ochrepts
		Regosols	Fluvents
			Psamments

several levels to show how they relate. From its inception, soil taxonomy was designed to serve the soil survey needs. Recently a key modified from Buol *et. al* 1998 to soil orders has been suggested by Velayutham and Bhattacharyya (2000).

ADVANTAGES OF SOIL TAXONOMY

- It maintains natural body concept and is based on soil properties.
- It has a unique nomenclature, which gives a definite connotation of major characteristics of soil. The nomenclature is derived mainly from Greek or Latin languages. Once it is understood it is the most logical system in understanding and interpreting taxon.
- It is based on soil properties as they are found today.
- Soil genesis is not ignored, since the criteria to place a soil in a group are based on soil properties. All the physical, chemical and biological properties are used as criteria.

DIAGNOSTIC HORIZONS

A diagnostic horizon is one, which is formed as a result of pedogenic processes and having features that can be measured in terms of measurable soil properties. These horizons are used to differentiate among soil orders, suborders, great groups and subgroups. Thus diagnostic horizons are used to define soil classes at various categorical levels. Diagnostic horizons found at the surface of the soil are called epipedons (Gr. Epi meaning over or upon and pedon soil). The epipedon is not

Table 6.2. Epipedons and their characteristics

Mollic epipedon	(L. Mollis, soft) Dark colored, high base saturation (more than 50%), contains more than 1% organic matter, more than 25 cm thick.
Anthropic Epipedon	Man made horizon formed during use of soil by people for long periods. High in available P. (more than 250 ppm of citric acid soluble P_2O_5)
Umbric epipedon	(L. umbra, shade, hence dark) similar to mollic epipedon but having less than 50% base saturation.
Ochric epipedon	(Gr. Ochrus, pale) light colored surface horizon (color values more than 5.5 dry or 3.5 moist). Too low in organic matter (less than 1%)
Histic epipedon	(Gr. histos, tissue) very high in organic matter (12–30%), saturated with water during some part of the year.
Plaggen Epipedon	(Ger. Plaggen, sod) is a man made surface horizon 50cm or thicker that has been produced by continued manuring. High in humus.
Melanic epipedon	A thick black horizon at or near the soil surface which contain 6% or more organic carbon as weighted average or 4% or more organic carbon in all layers.

Table 6.3. Subsurface horizons and their characteristics

Agrillic horizon	(L. argilla, white clay) silicate clays accumulation. This is formed by illuviation of clay, In general, this is a B-horizon that has at least 1.2 times as much clay content as compared to horizon above.
Natric horizon	(NL. Naturium, sodium, implying presence of sodium), is an argillic horizon high in sodium, it has a prismatic or columnar structure, ESP is more than 15.
Spodic horizon	(Gr. Spodos, wood ash composed of organic matter, Fe and Al oxides accumulation.
Cambic horizon	(LL. cambiarc, to exchange) is an altered horizon in which the texture of the fine earth fraction is very fine sand, the physical condition is the result of movement of the soil particles by frost, roots or animals or aggregation of soil particles into peds.
Oxic horizon	(F. Oxide, oxide) Highly weathered mixture of Fe, Al oxides and nonsticky type silicate clays. Oxic horizons are found generally in very old, stable geomorphic surfaces.
Argic horizon	(L. ager, field). Organic or clay accumulation below plow layer. An illuvial horizon formed due to long continued cultivation.
Albic horizon	(L. albus white), is one from which clay and free iron oxides have been removed. The color of the horizon is determined by the color of the primary sand and silt particles.
Calcic horizon	Horizon of accumulation of CaCO_3 or calcium and magnesium carbonate may be in the C-horizon or any other horizon above.
Gypsic horizon	Horizon of accumulation of gypsum, is iron cemented or weakly cemented horizon with secondary calcium sulfate that is 15 cm or more thick, has at least 5% more gypsum than the C-horizon.
Salic horizon	Accumulation of salt is a horizon having secondary enrichment of salts soluble in cold water. It contains 2% salt, and the product of its thickness in cm and salt percentage by weight is more than 60.

necessary the A horizon, but the layer of soil formed at the surface is usually up to 15 to 18 cm from the surface (surface soil). Horizons formed in lower layers of soil are called subsurface diagnostic horizons. The main characteristics of epipedons are given in Table 6.2.

Hardpan Horizons

- Duripan (L. durus, hard and pan, meaning hard pan): Hardpan, cemented by silica precipitated when water evaporates into dry substrata. Common in arid regions. Duripans prevent penetration of plant roots.

- **Fragipans** (L. fragilis brittle, and pan, brittle pan) Brittle pan loamy textured and weakly cemented. Fragipans are layers with high bulk density and low permeability. They are formed in humid climates. Fragipans are hard and brittle when dry and soften when wet. Few plant roots penetrate fragipans.
- **Plinthite** (Gk plinthos, brick), is an iron rich, humus poor mixture of clay with quartz. Plinthite is hard when dry and may form ironstone. Formation of ironstone involves bonding between positively charged iron oxides and negatively charged kaolinite clays. Drying results in a reduced bond length and imparts a stable position that is broken by rewetting.
- **Petro calcic horizon:** It is cemented calcic horizon along with carbonates. It is not easily penetrable.
Petro gypsic horizon: Cemented strongly by gypsum, which restricts the penetration of roots.
- **Placic horizon:** Cemented by iron, iron and manganese or by iron and organic matter.

Diagnostic Contacts

These are hard layers, which restrict penetration of plant roots.

- **Lithic contact:** A boundary between soil and underlying material that has hardness of more than 3 on Mhos scale.
- **Paralithic contact:** A horizon between soil and underlying material with a hardness of less than 3 on Mhos scale. This permits penetration of roots at irregular intervals.
- **Petroferric contact:** A boundary between soil and an underlying layer of iron cemented material.

Diagnostic Features

These include soil moisture regimes (SMR) and soil temperature regimes (STR). These regimes control plant growth and also provide specific environment under which a soil has developed.

Soil moisture regimes: Soil moisture regimes are expressed in terms of water held at a tension of less than 15 bars, at varying depths (10-60 cm) depending upon soil texture during the year. Five soil moisture regimes have been identified.

- **Aquic** (L. aqua, water): A condition when the soil pores are filled with water. The conditions are not favourable for plant growth due to anaerobic conditions.
- **Aridic** (L. aridus, dry): Where the soil temperature is above 5°C up to a depth of 50 cm in soil and water moves into soil moisture control section (SMCS). (20-60 cm depth in soil) for a very short period in a year.
- **Torric** (L. torridus, hot and dry): Where the soil temperature at a depth of 50 cm is above 8°C and SMCS remains dry for more than 90 consecutive days. This is common in arid regions.
- **Udic** (L. udus, humid): The udic moisture regime is common in the soils of humid climates that have well distributed rainfall. Water moves into the soil almost throughout the year. The soil moisture at varying depths (20-60 cm) is not dry in any part for more than 90 days.
- **Ustic** (L. ustus, burnt, dryness): This regime is intermediate between the aridic and the udic regimes. Moisture is present at a time when conditions are suitable

for plant growth.

- **Xeric** (Gr. Xeros, dry): This regime is characteristic of Mediterranean regions where winters are moist and cool and summers are warm and dry.

Soil temperature regimes: (STR): Soil temperature regime is expressed at 50 cm of soil depth or at boundary between soil and coherent underlying material for example: lithic contact or paralithic contact. The temperature range from 5° to 35° C is important in determining the degree of biological, chemical activities and physical processes going on in soils. (Sehgal *et al*, 1987), and used in soil classification systems. Soil temperature regimes play an important role in classifying soils at the family and suborder categoric levels. (Soil survey staff, 1975). Soil temperature regimes are as follows:

Frigid: The mean annual soil temperature is lower than 8° C. The difference between mean winter and mean summer soil temperature is more than 5° C.

Mesic: The mean annual soil temperature is between 8 to 15°C. The difference between mean summer and mean winter soil temperature is more than 5° C.

Thermic: The mean annual soil temperature is between 15 to 22° C and the difference between mean summer and mean winter soil temperature is more than 5° C.

Hyperthermic: The mean annual soil temperature is 22°C or higher.

HIGHER AND LOWER CATEGORIES OF THE CLASSIFICATION SYSTEM

The modern classification systems are based upon the study of soil profile. A soil profile reflects influence of soil forming factors and processes. The higher categories are order, suborder, great soil group and subgroup. They give a general understanding of the soils over large areas. The higher categories are designed for use where broad generalizations are needed. The lower categories are families, series, types and phases. The lower categories serve more specific needs. They are important in identifying local differences. Thus, productive capacities of soils may be found.

HIGHER CATEGORIES OF SOIL TAXONOMY: ORDER, SUBORDER AND GREAT GROUP

Soil order: This category is based on soil forming processes as indicated by the presence or absence of major diagnostic horizons. Soils in one group are closely similar to their genesis. These features are characteristic of major processes of soil formation affected by climate. There are eleven soil orders: AAVAMIHOUSE is a compound word suggested to facilitate naming of the orders. Their names, formative element, derivation pronunciation and major characteristics have been presented in Table 6.4.

Important Characteristics of Soil Orders

Entisols (Origin: from recent soils, without pedogenic developed horizons)

Table 6.4. Soil orders with their major characteristics.

Name (Formative element)	Derivation	Pronuncia- tion	Major characteristics
Entisols(ent)	-	Recent	Little profile development, ochric epipedon
Inceptisols(ept)	L.inceptum, beginning	Inception	Beginning of profile development, orchric or umbric epipedon cambic horizon
Mollisols(oll)	L.mollis, soft	Mollify	Mollic epipedon
Alfisols(alf)	-	Pedalfer	Argillic or natric horizon, high to medium base saturation
Udisols(ult)	L.ultimus, last	Ultimate	Argillic horizon, low base saturation
Vertisols(ert)	L.verto, turn	Invert	High in swelling clays, deep cracks when soil dry
Oxisol(ox)	Fr.oxide,oxide	Oxide	Oxic horizon, no argillic horizon, highly weathered
Aridisols(id)	L.aridus, dry	Arid	Dry soil, ochric epipedon, sometimes argillic or natric horizon
Spodosols(od)	Gk.spodos, wood ash	Podozol, odd	Spodic horizon commonly with Fe, Al and humus
Histosols(ist)	Gk.histos, tissue	Histology	Peat or bog, > 30 % organic matter
Andosols	Modified from Ando	Andesite	From volcanic ash, dominated by allophanes

- No developed horizon exists. Entisols are identified by the absence of distinct pedogenic horizons.
- Entisols range from sand to river deposited clays.
- Their agricultural productivity varies.
- Restrictions on their depth, clay content or water balance limit their intensive use.

Inceptisols: (Origin: Latin, inceptum, beginning, inception)

- Inceptisols are soils in an early stage of development.

- They are more weathered and developed soils than are entisols. They are common in mountains and in humid and sub-humid areas.
- Any soil with a plaggen epipedon (at least 50cm of artificial soil produced by manuring) is considered to be an inceptisol.

Aridisols: (Origin: Latin, aridus, dry, dry more than 6 months a year)

- Soils found in dry climates and short periods of wetness.
- A lack of water reduces leaching of basic cations and favours accumulation of soluble salts.
- Accumulation of gypsum, calcium carbonate, duripans are common features of profiles developed in arid regions.
- Aridisols are among the most productive soils when they are irrigated and cultivated.

Mollisols: (Origin: Latin, mollis, soft, organic-rich surface horizons)

- Mollisols are dark colored soils of grasslands. They are characterized by mollic epipedon that is dark, thick, strong in structure due to organic matter and saturated with basic cations.
- They are fertile soils, because of high humus and clay content.

Ultisols: (Origin: Latin, ultimus, last, highly leached, clay accumulation in B-horizon)

- Ultisols are the moist region soils. They are low in basic cation saturation.
- They are developed in humid climates, tropical to subtropical temperatures.
- There is an accumulation of clay, surface horizons dark with humus and a leached layer (E).
- Fertilization and liming are necessary to produce moderate to high yields.

Vertisols: (Origin: Latin, verito, turn, self-expanding clays)

- These soils expand and contract because of their high clay content and are difficult to cultivate.
- Vertisols have deep A-horizons, vertical movement due to dislocation during wetting drying cycles occurs.
- When wet, soils are sticky, when dry, they are hard.
- These soils are fertile with high cation exchange capacity.

Oxisols: (Origin: French, oxide, very highly oxidized throughout profiles)

- They are most extensively weathered soils, up to several meters in depth found in tropical to subtropical climates.
- Due to weathering of primary minerals, silica is lost and such soils are rich in iron and aluminum oxide residues, which have very low solubility. Oxic epipedon is present.
- Heavy fertilization including micro nutrients is required.
- They have good potential for food and fibre production.

Alfisols: (Origin: Coined from pedalfer, al for aluminum and fer for ferric iron, movement of Al, Fe and clay into the B-horizon)

- Alfisols develop argillic horizon (clay accumulation) due to high rainfall. Natric horizon may also occur.
- The basic cation saturation is high (more than 50 per cent).
- Alfisols are naturally productive soils. If relief and climate are favorable, they may produce well.

Spodosols: (Origin: Greek, spodos, wood ash, grey colour of E-horizon).

- They are characterized by subsurface spodic horizon (accumulation of organic matter and iron and aluminum oxides).
- The eluvial horizon (above spodic horizon) is white in colour and is therefore called as “Wood ash”. Spodosols form on coarse textured, acid, parent materials subjected to leaching under conditions of high rainfall.
- Spodosols are not naturally fertile. When fertilized, these soils can become productive.

Histosols: (Origin: Greek, histos, tissue, organic soils)

- These are organic soils developed under a water-saturated environment.
- They contain minimum of 12 per cent organic carbon if the mineral portion has no clay, increasing to 18 per cent if the mineral portion is 60 per cent or more clay, for soils formed in water.
- Formation of histosols is common in wet areas having stagnant marshes and swamps.
- There are problem in management of histosols. This may be due to reduction in soil volume with drainage when land surfaces have dropped in elevation. For seed - bed preparation, the soil may not be rolled to firm it rather than plowed to loosen it.

Andisols: Tentative (Origin: Japanese, ando-an, black; do, soil volcanic ash content).

- Andisols are weakly to moderately developed soils. After extensive weathering, they may become soils of other orders.

Table 6.5. Suborders in soil taxonomy

Order	Suborders in soil taxonomy
Entisols	Aquents, Arenets, Fluvents, Orthents, Psamment
Inceptisols	Andepts, Aquepts, Ochrepts, Plaggepts, Tropepts, Umbrepts
Mollisols	Albolls, Borolls, Rendolls, Udolls, Ustolls, Xerolls
Alfisols	Aqualfs, Boralfs, Udalfs, Ustalfs, Xeralfs
Ultisols	Aquults, Humults, Udults, Ustults, Xerults
Oxisols	Aquox, Perox, Torrox, Udox, Ustox
Vertisols	Torrerts, Uderts, Usterts, Xererts
Ardisols	Argids, Orthids
Spodosols	Aquods, Ferroids, Humods, Orthods
Histosols	Fibrists, Hemists, Saprist, Folists
Andisols	Aquands, Cryands, Torrands, Udands, Ustands, Xerands, Vitrands

- There is rapid weathering and mineral transformation in early stages.
- These minerals form from volcanic material and amorphous clays (allophane, imogolite, ferrihydrite).
- These soils are productive when managed well. The amorphous allophane clays have high cation exchange capacity.

SUBORDER

Suborders suggest genetic homogeneity. Suborders within a soil order are differentiated on the basis of additional soil properties and horizons resulting from differences in soil moisture, soil temperature, and dominating influence of physical and chemical characteristics. Sixty suborders have been identified. Names of different suborders have been presented in Table 6.5. Formative element in suborders, their derivation and major characteristics have been presented in Table 6.6.

GREAT GROUP

Great groups are subdivisions of suborders. They have been established largely on the basis of differentiating soil horizons and soil features (Diagnostic horizons). Soils in a given great group have the same kind and arrangement of these horizons. More than 240 great groups have been identified. They are presented in Table 6.7.

Table 6.6. Formative elements in suborders.

Formative elements	Derivations	Characteristics
Alb	L. akbu, white	Presence of albic horizon
And	Modified from Ando	Volcanic ash
Aqu	L. Acqua, water	Characteristics associated with wetness
Ar	L. arare, to plow	Mixed horizon
Arg	L. argilla, white clay	Presence of argillic horizon
Bor	Gk. Boreas, northern	Cool
Cry	Gk. Kruos, icy cold	Cold
Ferr	L. ferrum, iron	Presence of iron
Fibr	L. fibra, fiber	Least decomposed stage
Fluv	L. fluvius, river	Flood plains
Fol	L.folia, leaf	Mass of leaves
Hans	Gk. Hemi, half	Intermediate stage of decomposition
Hum	L. humus	Presence of organic matter
Ochr	Gk. Base of ochros, pale	Presence of ochric epipedon
Orth	Gk. Orthos, true	The common ones
Pernd	Continuously humid	Of year round humid climates
Plagg	Modified from	Presence of plaggan epipedon Ger.plaggen
Psamm	Gk. Psamimos, sand	Sand textures
Rand	-	Rendzina-like
Sapr	Gk. Sapro, rotten	Most decomposed stage
Torr	L. torridus, hot and	Usually dry; tropepts: humid and dry warm, tropical
Nd	L. udus, humid	Of humid climates

Table 6.7. Great groups in soil taxonomy

Suborder (5)	Great group (36)
1 Aquepts	Sulfaquepts, Hydraquepts, Cryaquepts, Fluaquepts, Tropaquepts.
Arents	Pasmmaquepts, Haplaquepts
Psamments	No great group
	Cryopsamments, Torripsamments, Quartzipsamments, Udipsamments, Tropopsamments, Xeropsamments, Ustipsamments
4. Fluvents	Cryfluvents, Xerofluvents, Ustifuvents, Torrifluvents, Tropofluvents, Udifluvents
5 Orthents	Cryorthents, Torriorthents, Xerothents, Troporthents, Udorthents, Ustorthents
<i>Order-Inceptisols</i>	<i>Great group (33)</i>
<i>Suborder (6)</i>	
1 Andepts	Sulfaquepts, Placaquepts, Halaquepts, Fragiaquepts, Cryaquepts, Plinthaquepts, Andaquepts, Tropaquepts, Humaquepts, Haplaquepts
2 Aquepts	Cryandepts, Durandepts, Hydrandepts, Placandepts, Vitrandepts, Eutrandepts, Dystropepts,
3 Plaggepts	No great group
4 Tropepts	Humitropepts, Sombritropepts, Ustropepts, Europepts, Dystropepts
5 Ocherepts	Fragiochrepts, Durochrepts, Crychrepts, Ustochrepts, Xerochrepts, Eutrochrepts, Dystrochrepts
6 Umbrept	Fragiumbrepts, Cryumbrepts, Xerumbrepts, Haplumbrepts
<i>Order-Alfisols</i>	<i>Great group (37)</i>
<i>Suborder (5)</i>	
1 Aqualfs	Plinthaqualfs, Natraqualfs, Duraqualfs, Tropaqualfs, Fragiaqualfs, Glossaqualfs, Albaqualfs, Umbraqualf, Ochraqualfs
2 Boralfs	Paleboralfs, Fragiboralfs, Natriboralfs, Cyroboralfs, Eutroboralfs, Glosssoboralfs
3 Ustalfs	Durustalfs, Plinthustalfs, Natrustalfs, Paleustalfs, Rhodoustalfs, Haplustalfs
4 Udalfs	Argudalfs, Natrudalfs, Ferrudalfs, Glossudalfs, Fraglossudalfs, Fragiudalfs, Paleudalfs, Rohdulafs, Tropudalfs, Hapludalfs
5 Xeralfs	Durixeralfs, Plinthoxeralfs, Natrixeralfs, Rhodoxeralfs, Palexeralfs, Haploxeralfs
<i>Order-Vertisols</i>	<i>Great groups (6)</i>
<i>Suborders (4)</i>	
1 Torrerts	No great group at this time
2 Uderts	Chromuderts, Pelluderts
3 Uderts	Pellusterts, Chromusterts
4 Xererts	Chromoxererts, Pelloxererts
<i>Order-Aridisols</i>	<i>Great groups (11)</i>
<i>Suborders (2)</i>	
1 Orthids	Salorthids, Paleorthids, Durorthids, Gypsiorthids, Calciorthids, Camborthids

Table 6.7. Continued

Suborder (5)	Great group (36)
2 Argids <i>Order-Mollisol</i> <i>Suborders (7)</i>	Durargids, Nadurargids, Natrargids, Paleargids, Haplargids <i>Great groups (32)</i>
1 Albolis	Natrallbolis, Argialbolis
2 Aquolls	Cryaquolls, Duraquolls, Natraquolls, Calciaquolls, Argiaquolls, Haplaquolls
3 Rendolls	No great group presently recognised
4 Xerolls	Durixerolls, Natrixerolls, Palexerolls, Calciixerolls, Argixerolls, Haploxerolls
5 Borolls	Paleborolls, Crybrollos, Natriborolls, Argiborolls, Vermiborolls, Calciborolls, Haploborolls
6 Ustolls	Durustolls, Watrustolls, Paleustolls, Calciustolls, Argiustolls, Vermustolls, Haplustolls
7 Ustolls <i>Order-Spodosol</i> <i>Suborder (5)</i>	Paleudolls, Argiudolls, Vermudolls, Hapludolls <i>Great group (17)</i>
1 Aquods	Fragiaquods, Cryaquods, Duraquods, Placaquods, Tropaquods, Haplaquods, Sideraquods
2 Ferrods	No great group presently recognised
3 Humods	Placohumods, Tropohumods, Fragihumods, Cryhumods, Haplohumods
4 Orthods <i>Order-Ultisols</i> <i>Suborder (5)</i>	Placorthods, Fragiorthods, Cryorthods, Troporthods, Haplorthods <i>Great group (24)</i>
1 Aquults	Plinthaquults, Fragiaquults, Albaquults, Paleaquults, Tropaquults, Ochraqults, Umbraqults
2 Humults	Sombrihumults, Palehumults, Plinthohumults, Tropohumults, Haplohumults
3 Udults	Fragiudults, Plithudults, Paleudults, Rohodoudults, Tropudults, Hapludults
4 Ustults	Plinthustults, Paleustults, Rhodustults, Haplustults
5 Xerults	Palexerults, Haploxerults <i>Great group (18)</i>
1 Aquox	Gibbriaquox, Plinthaquox, Ochraquox, Umbraquox
2 Torrox	No great group at present
3 Humox	Sombrihumox, Gibbsihumox, Haplohumox, Acrohumox
4 Ustox	Sombriustox, Acrustox, Eustrustox, Haplustox
5 Orthox	Sombriorthox, Gibbsiorthox, Acrorthox, Entrortox, Umbrorthox, Haplorthox <i>Great group (20)</i>
<i>Order-Histosols</i> <i>Suborders (4)</i>	
1 Folists	Cryofolists, Tropofolists, Borofolists
2 Fibrists	Sphaguofibrists, Cryobrists, Borofibrists, Tropofibrists, Medfibrists, Luvifibrists
3 Hemists	Sulfohamists, Sulfihemists, Luvihemists, Cryohemists, Borohermists, Tropohemists, Medihemists
4 Saprists	Cryosaprists, Borosdprists, Troposaprists, Medisaprists

Table 6.8. Formative elements of Great groups

Formative element	Derivation	Connotation	Formative element	Derivation	Connotation
Acr	Acrolith	Extreme weathering	Med	Medium	Of temperate climate
Agr	Agriculture	An argic horizon	Nadur	-	Sodic duripan
Alb	Albino	An albic horizon	Natr	Natrium	Presence of nitric horizon
And	Ando	Volcanic ash	Ochr	Ochros	Presence of ochric epipedon
Arg	Argilla	An argillic horizon	Pale	Old	Excessive development
Bor	Boreas	Cool	Pelt	Dusky	Low chroma
Calc	Calcium	A calcic horizons	Plac	Flat	Presence of thin pan
Camb	Change	A cambic horizon	Plagg	-	Presence of plaggen epipedon
Chron	Chroma	Bright colour	Plinth	Brick	Presence of plinthite'
Cry	Crystal	Cold	Psanam	Sand	Sand texture
Dur	Durable	Duripan	Quartz	Quartz	High quartz content
Dystr	Dystrophic	Low basic cation saturation	Rhod	Rose	Dark red color
Entr, eu	Eutrophic	High basic cation saturation	Sal	Salt	Presence of salic horizon
Ferra	Ferrung	Presence of iron oxide	Sider	Siderita	Presence of free iron oxide
Fluv	Fluvial	Flood plain	Sombr	Somber	A dark colored horizon
Frag	Fragile	Presence of fragipans	Sphagn	Bog	Presence of pead mass
Fragloss	-	Tonngued' fragipan	Sulf	Sulfur	Presence of sulfides
Gibbs	Gibbsite	Presence of gibbsite in sheets	Toro	Torrid	Hot and dry torric regime
Gyps	Gypsum	Presence of gypsic horizon	Trop	Tropical	Humid and warm
Hal	Salt	Salty	Ud	Humid	Undic moisture regime

Table 6.8. Continued

Formative element	Derivation	Connotation	S. No.	Formative element	Derivation	Connotation
Hapl	Haploid	Maximum horizon development	46.	Umbr	Umbrella	Presence of umbric epipedon
Hum	Humus	Presence of humus	47.	Ust	Burnt	Ustic moisture regime
Hydr	Hydra	Presence of water	48.	Verm	Worm	Mixed by animals
Kand	-	Low activity clay	49.	Vitreous	Vitreous	Presence of volcanic glass
luv	Luva	Illuvial	50.	Xerophyt	Xerophyta	Xeric moisture regime

Formative elements of great groups have been presented in Table 6.8.

LOWER CATEGORIES OF SOIL TAXONOMY - SUBGROUP, FAMILY, SERIES

Subgroup: Each soil great group is divided into three kinds of subgroups. One representing the central (Typic) concept of this soil groups, a second which has properties that tend towards other orders, suborders or other great groups; and a third which has properties other than those listed in first two categories. More than 1200 subgroups are recognized.

Family: Soil families are separated within a subgroup primarily on the basis of soil properties important to the growth of plants. Some of these soil properties are texture, mineralogy, pH, and distribution of rainfall and structure.

Series: The name of series has no pedogenic significance. It represents a prominent geographic name of a river, town or an area where the series was first recognized. Soils in the same series have similar properties such as color texture, structure, consistence, thickness, pH, number and arrangement of horizons and their chemical and mineralogical properties.

Name of Subgroup

A Typic subgroup is defined as a taxon representing the ‘central concept’ of the great group. Other taxa are defined according to their possession of one or

Table 6.9. Extragrade formative elements

Anthropic	Gr-anthropos, man	Anthropic epipedon
Lithic	Gr-Lithos, stone	Shallow lithic, contact person
Petrocalcic	Gr-petra, rock and calcic	Petrocalcic horizon present
Petroferric	Gr-rock and, Liferrum iron	Petroferric contact present
Terric	L-terra, earth	Mineral substratum

Table 6.10. Classification of family nomenclature

Textural classe	Mineralogical classes	Soil temperature classes	Mean annual temperature (°C)
Sandy	Illitic	Frigid	<8
Loamy	Smectitic	Mesic	8-15
Clayey	Montmorillonitic	Thermic	15-22
And others	Siliceous and others	Hypothermic	>22

more characteristics of other orders, suborders or great groups. For example, a Lithic haplustalf indicates presence of stones which differentiates it from its central concept ‘Typic’. Similarly, a Vertic haplustalf has defined properties that are common to vertisols but these properties are not well expressed enough to classify the soil in the order vertisol.

Within some great groups soils have properties that they do not intergrade toward defined categories. These soils are identified by extragrade formative elements. Some of them with their formative element, derivation and connotation are presented below in Table 6.9.

Family Nomenclature

Family criteria are of three kinds: textural classes, mineralogy classes and soil temperature classes. They are presented in Table 6.10.

Series Name

Each series is given a name usually from some town, village and river where the series was first recognized.

NOMENCLATURE ACCORDING TO SOIL TAXONOMY

The system contains six categories. They are order, suborder, great group, subgroup, family and series. The names of classification units are combinations of syllables derived from Latin or Greek word.

- The names of orders are combinations of (a) formative elements, which define the characteristics of the soils, and (b) the ending sol.
- Once soil order is established, consider the nature and properties of only the soils within a given order in order to determine the suborder, within a specific order. All suborders and their formative elements are listed in Table 6.2 and 6.3 respectively.
- Determine Great Groups within a suborder. All great groups presently recognized and their formative elements are listed in Table 6.4 and 6.5 respectively. These Tables 6.4 to 6.8 can be used to generate names of soil to the level of great groups by
 - (a) Taking first the entry of the formative element of great group
 - (b) Then the suborder formative element as the second part,
 - (c) Then the order formative element is added to the end, to complete the name.For example, a soil having silicate clays and high in sodium, i.e. nitric horizon

(natr-formative element of great group), with argillic horizon (arg-formative element of suborder group) and soils are dry for more than 50% of the year (id-formative element of order, Aridisol). Putting these together, we arrive at the name natr+arg+id=Natrargid.

SOIL MAPPING UNITS

The soil mapping units are identified through profile examinations. In soil survey, series, types, phases are mapped. Soil complex, soil association, catena and legend are also mapping units.

Soil series: It represents a prominent geographic name of a river, town or area where the series was first recognized.

Soil types: It is a subdivision of series based on the texture of surface soil.

Soil phase: They mainly indicate differences of practical significance. Phases are subdivisions of any category of soil classification in respect of slope, erosion, stoniness and salinity. For example, at order level eroded inceptisol, at suborder level stony orthids, at great group level a sandy Typic haplustalf and so on.

Soil association: A grouping of soils of different kinds, which may or may not be from the same order, which occur in the same area. Soil association helps to determine a combination of land use pattern that must be adopted to support a profitable agriculture. A toposequence is a small soil association with differences related to topography.

Soil complex: When different types or series of soils occur in small areas in an intricate pattern, they cannot be separately mapped. In such cases, the percentage occupied by each composing unit is shown on the map. Such a presentation on a soil map is called a soil complex.

Catena: Soils developed from same parent material may differ in their drainage or relief. The soils may be well drained, imperfectly drained or poorly drained. This relationship on the basis of difference in drainage and relief is known as catena.

Legend: It is a list of defined mapping units with their symbols. The units in the legend should be such that are suited to the details of the natural soil pattern and to the scale of the map.

IMPORTANT SOIL GROUPS OF INDIA

Alluvial Soils

These soils form the largest and important soil group for crop production. The characteristics of these soils vary. Their color, texture and development in regard to profile differentiation differ depending upon the parent materials in their catchment areas. Most of the fresh alluvia show no horizonation, while the older alluvium shows distinct horizonation. Thus extreme of variations are possible in these soils. In India, these soils are found in Indo-Gangetic plains. Such deposits (called alluvium) may be distinguished into different groups depending on the nature and places of their deposition as:

Coastal alluvium: Characterized by recent deposits of alluvial origin. Thus

they do not show prominent horizon differentiation. These soils are fertile. The composition and mineralogy of these soils are influenced by parent material. Their characteristics may be influenced by sea water and suffer from problems of salinity.

Deltic alluvium: They represent the heterogeneous type of sediments brought by rivers and deposited at their mouths. The Gangetic alluvium at the mouth of the Ganges, which is swampy shows considerable accumulation of organic matter, while the other alluvium, which is extensively cultivated and cropped, shows much less accumulation of organic matter.

Lacustrine alluvium: The deposits formed in lakes. These deposits may be coarse materials to fine silts and clay deposited from standing waters. This results in the development of fertile soils as the lakes dry.

Recent alluvium: Deposits by river flowing stream, which are of recent origin. Their characteristics are governed by the nature of parent material and water.

Old alluvium: The depth of alluvium is great and may extend more than hundred meters. These water deposited sediments are old, though newer deposits are continuously being added. The texture is silty, a well-formed B-horizon is met with deposition of lime might result in strong cementation. These soils, if not affected by salts or poor drainage, are fertile and respond well to manuring.

According to soil taxonomy the common orders, suborders and great groups of alluvial soils are as follows:

Order	Suborder	Great Group
Entisol	Fluents	Ustifluents, Udifluents, Torrifluents
	Aquants	Haplaquents, Ustipsamments
	Psamments	Udispsamments, Torripsamments
	Orthents	Calciorthents
Inceptisols	Ochrepts	Ustochrepts, Eutrochrepts
Alfisol	Ustalfs	Haplustalfs, Natrustalfs
Aridisol	Orthids	Calciorthids, Camorthids, Salorthids

Black Soils (Grumusols)

- These soils occur in areas ranging from semiarid to subhumid climates.
- They possess a characteristically dark color, ranging from dark brown to deep black.
- Their limitation for crop production is because of their poor workability (tillage operations, and poor drainage).
- They are high in clay content, clay mostly belong to montmorillonitic group, are sticky and plastic when wet. They show strong swelling and shrinkage with changes in moisture content and produce deep and wide cracks.
- The dark color of these soils is not due to high organic matter content. The black color may be due to presence of titaniferous-magnetite compounds and/or clay-humus complexes.
- They may be classified as shallow (possessing a depth of 30 cm or less, medium (30-100cm) and deep (100-200cm or even more) black soils.

According to soil taxonomy the common orders, suborders and great groups of black soils are as follows:

Order	Sub order	Great group
Vertisol	Torrerts Usterts	Torritorrerts, Usttorrerts Torriusterts, Ustusterts.

Red Soils

- They are well-drained soils, with clay enriched subsoil developed from granite, gneiss or schists under subtropical climate.
- In general, red soils are derived from granites and gneisses. The other rock formations from which red soils are developed are sandstones, hornblende and mica schists, acid traps, quartazites and shales. In some red soils lime concretions in the form of nodules are found. The normal red soils have a pH around neutrality or acidic side. The A-horizon is dark reddish brown while B-horizon may have a dark brown color.
- The clay minerals become coated with red hematite or yellow limonite forming a reddish-yellow soil. Impure iron, alumina-silica concretions and quartz are common constituents of red soils.

According to soil taxonomy the common orders, suborders and great groups of red soils are as follows:

Order	Sub order	Great group
Alfisol	Ustalfs Ustalfs	Haplustalfs Rhodustalfs, Paleustalfs
Ultisols	Ustults Ustults Aqults	Haplustults Rhodoustults Ochraqults

Laterite Soils

- Buchanan (1807) used the term ‘laterite’ for industrial clay of brick red color rich in iron material. This material is quite soft but on exposure to air, it becomes very hard. The soil has a typical vesicular honey comb structure. Robinson has suggested the term ferralite for lateritic soil.
- The siliceous matter of rock is leached away and sesquioxides are left behind and converted into irreversible iron and aluminum oxides.
- They have reddish color with maximum intensity in the B-horizon, deeply weathered and dominance of kaolinitic minerals.

According to soil taxonomy the common orders, suborders and great groups of laterite soils are as follows:

Order	Sub order	Great group
Oxisols	Not common	
Ultisols	Aquults Uduults	Plinthaquults Plinthuduults, Tropuduults

Salt Affected Soils

- These are confined mainly to arid and semi-arid regions.
- Salts may originate in the soil itself or by underground water. Sodium adsorption ratio (SAR) increases as a result of adsorption of sodium on the soil exchange complex. This results in the formation of alkali soils. During summer months, salts are deposited on the surface due to capillary rise of water.
- Because of high temperature of arid regions, water is evaporated and a white crust of salts accumulates near the surface. This results in the formation of saline soils.

According to soil taxonomy the common orders, suborders and great groups of salt affected soils are as follows:

Order	Sub order	Great Group
Aridisol	Orthids	Salorthids, Comborthids, Calciorthids
Inceptisol	Aquepts	Halaquepts
Alfisol	Ustulfs	Natrustalfs, Natraqualfs

Desert soils

- These soils are found characteristically in arid regions. A large area of desert region occurs in western Rajasthan, Haryana and Punjab. Quartz, feldspars and hornblende are common minerals found in these regions.
- Physical weathering plays dominant role in their formation. The soils are composed of sand. They are light in color. Both water and wind erosions are severe.
- The A-horizon is usually absent and B-horizon is weakly developed.

According to soil taxonomy the common orders, suborders and great groups of desert soils are as follows:

Order	Sub order	Great group
Aridisols	Argids Orthids	Haplargids Salorthids, Paleorthids, Gypsiorthids,
	Calciorthids, Camborthids	
Entisols	Psamments Fluvents Orthents	Torripsamments, Ustipsamments Ustifluvents, Torrifluvents Torriorthents, Ustorthents

Podzol Soils

- Podzol derives its name from the Russian word Zola meaning ash, that resembles the distinguishing bleached ash grey A2-horizon of podzols.
- These soils are formed under acidic conditions in humid regions.
- Leaching of bases and sesquioxides and their translocation into B-horizon is a common feature.

According to soil taxonomy the common orders, suborders and great groups

Table 6.11. The extent, distribution of the different soil classes in the Soil Map of India and their equivalents according to the new USDA system

Soil classification unit as in map	Extent (km²)	Distribution (States)	Equivalent according to the the new USDA system of classification
Red loamy soils	2,13,271	Andhra Pradesh, Tamil Nadu, Karnataka, Kerala, Madhya Pradesh, Orissa	Paleuslalfs Rhodustalfs Haplustalfs
Red sandy soils	3.30.590	Tamil Nadu, Karnataka, Andhra Pradesh	Haplustalfs Rhodustalfs
Laterite soils	1,30,066	Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, Orissa, Maharashtra Goa, Assam	Plinthaquults Plinthustults Plinthudults Oxisols
Red and yellow soils	4,03,651	Madhya Pradesh, Orissa Ochraquults	Haplustults
Shallow black soils	31,532	Maharashtra	Rhodustults Ustorthents Ustopepts
Medium black soils	4,30,383	Maharashtra, Madhya Pradesh, Gujarat	Pellusterts Chromusterts
Deep black soils	1,12,060	Maharashtra, Andhra Pradesh, Karnataka, Madhya Pradesh, Gujarat	Pellusterts Chromusterts Pelluderts
Mixed red and black soils	1,62,255	Karnataka, Tamil Nadu, Maharashtra, Madhya Pradesh	Association of Alfisols and Vertisols which cannot be separately mapped in the scale under reference
Coastal alluvium soils	54,403	Tamil Nadu, Kerala, Andhra Pradesh, Maharashtra, Gujarat	Haplaquents
Coastal sands	4,534	Orissa	Ustipsamments
Deltaic alluvium soils	87,045	Tamil Nadu, Andhra Pradesh, Orrissa, West Bangal	Quartzipsamments Tropaqualfs
Alluvial soils Khadar (recent alluvium)	3,56,720	Uttar Pradesh, Punjab, Bihar, West Bengal, Assam	Haplaquents Ustifluvents Udifluvents
Bhangar (old Alluvium)			
Alluvium soils (highly calcareous)	13,611	North-Eastern, Uttar Pradesh Bihar	Calciorthents
Calcareous sierozemic soils	45,080	Punjab	Calciorthids
Grey brown soils	1,01,572	Gujarat, Rajasthan	Calciorthids
Desert soil	1,54,423	Rajasthan	Calciorthids, Psamments
Rhegosolic			Lithic Entisols
Desert soils Lithosolic			
Terai soils	28,919	Uttar Pradesh, Bihar, West Bengal	Haplaquolls
Brown hill soils (over sandstones and shales)	81,242	Uttar Pradesh, Bhutan, Sikkim, Himachal Pradesh	Palchumults

Table 6.11 Continued

Table 6.11.

Sub-montane soils (Podsollic)	76,695	Uttar Pradesh, Jammu & Kashmir	Hapludalfs
Mountain meadow soils	59,790	Kashmir including Ladakh	Cryoborolls Cryochrepts
Saline and alkali soils	17,377	Uttar Pradesh, Punjab, Maharashtra, Karnataka, Tamil Nadu	Salorthids, Salargids, Natrargids, some of the Entisols and Vertisols are also salic or nitric
23. Peaty and saline peaty soils	2,720	Kerala	Histosols
24. Skeletal soils	79,151	Madhya Pradesh	Lithic Entisols
25. Glaciers and eternal snow	29,335	Uttar Pradesh, Kashmir	

Source : Velayutham and Bhattacharyya (2000).

of podzol soils are as follows:

Order	Sub order	Great group
Spodosols	Aquods	Haplaquods, Fragiaquods
	Ferroids	
	Orthods	Fragiorthods, Haplorthods

Peat and Marshy Soils

- These are organic soils. These soils develop under humid climate as a result of accumulation of organic matter.
- These soils show accumulation of pyrites, ferrous and aluminum sulphate in swampy areas. Pyrite is oxidized to sulphuric acid resulting in lowering of pH of these soils.
- Marshy soils are confined to depressions. They are developed under anaerobic conditions. Due to presence of ferrous iron and organic matter these soils develop bluish color.
- They are characterized by the presence of high organic matter, low base saturation and a low pH.
- These soils are found in the backwater areas of Kerala State. Small areas of peat accumulation at the surface occur in the northern parts of Bihar.

According to soil taxonomy the common orders, suborders and great groups of peat and marshy soils are as follows:

Order	Sub order	Great group
Histosols	Fibrists	Cryobrists, Tropofibrists Tropohemists, Cryohemists, Sulfohamists
	Hemists	

Table 6.12. Information of different categories of soil taxonomy in soil resource mapping of states on 1:250,000 scale**

States / Soil Information	T.G.A.*	Soil Orders	Sub Orders	Great Groups	Sub Groups	Families Map	Soil Units
Andaman & Nicobar Islands	196	4	8	11	37	42	
Andhra Pradesh	27506.8	7	11	18	46	132	238
Arunachal Pradesh	8374.3	5	10	16	30	79	46
Assam	7852	4	9	15	26	83	83
Bihar	17,387.7	5	9	19	38	72	175
Delhi	148.3	2	4	4	6	12	31
Goa	370.2	4	7	13	16	21	25
Gujarat	19602.4	5	11	20	45	124	370
Haryana	4421.2	4	6	11	20	27	199
Himachal Pradesh	5567.3	4	6	12	17	43	95
Jammu & Kashmir	22222.6	4	8	13	28		140
Karnataka	19179.1	7	12	18	28	56	141
Kerala	3886.3	5	10	19	29	38	38
Lakshadweep	32	1	2	4	6	6	
Madhya Pradesh	44344.6	5	7	11	26	130	851
Maharashtra	30769	5	8	10	18		356
Manipur	2232.7	4	8	13	22	29	19
Meghalaya	2242.9	4	8	14	25		24
Mizoram	2108.1	4	7	9	11		31
Nagaland	1657.9	4	6	8	14	72	34
Orissa	15570.7	4	10	17	41	98	159
Pondicherry	44	4	6	7	10	10	
Punjab	5036.2	4	7	11	14	124	124
Rajasthan	34223.9	5	8	16	32	86	375
Sikkim	709.6	3	7	12	26	69	69
Tamil Nadu	13005.8	6	12	20	44	94	285
Tripura	1048.6	5	9	13	23		43
Uttar Pradesh	29441.1	5	11	20	35		321
West Bengal	8875.2	3	10	19	36		115
Total	328057						

* in '000 ha; ** values indicate numbers
Source : Velayutham and Bhattacharyya (2000)

Table 6.13. Total soil orders, suborders, great groups and subgroups identified in India

Order	Sub order	Great group	Sub group
Alfisols	3	15	41
Aridisols	3	9	26
Entisols	5	23	51
Histosols	1	1	1
Inceptisols	4	16	72
Mollisols	3	6	14
Ultisols	3	11	23
Vertisols	2	4	18
Total	24	85	246

Source : Velayutham and Bhattacharyya (2000)

INDIAN SOILS IN US SYSTEM OF SOIL CLASSIFICATION

Soil Taxonomy (Soil Survey Staff, 1975, 1994, 1999) proposed by United States Department of Agriculture has been accepted as official soil classification system for India. In India the maximum area is covered under Inceptisols followed by Entisols, Alfisols, Vertisols and Aridisols. Table 6.11, 6.12 and 6.13 gives information of the extent of different orders and their soil taxonomy in different soil groups of India.

References and Suggested Readings

- Boul, S. W., Hole, H. D., and McCrackon, R. J. (1980) *Soil Genesis and Classification*. Oxford and IBH Publishing Co., New Delhi.
- Brady, N.C. (1995). *The Nature and Properties of Soil*. Prentice Hall of India Pvt. Ltd., New Delhi
- Sankaram, A. (1975). *Soil Science Genesis – Survey Classification*. The Textbook series in Agriculture Chemistry. The Bangalore Printing and Publishing Co. Ltd., Bangalore.
- Sehgal, J. (1996). *Pedology : Concepts and Applications*. Kalyani Publishers, New Delhi.
- USDA. 2000. Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys. U.S. Department of Agriculture Soil Conservation Service. Selected Government Publication. A Wiley – Inter-science Publication. John Wiley & Sons, New York.
- Velayutham, M. and Bhattacharyya, T. (2000). Soil resource management. pp.37–47. *Natural Resource Management for Agricultural Production in India*. 14–18, Feb. 2000, New Delhi.

QUESTIONS

Q. 1. Fill in the blanks:

- The soil _____ reflects the origin and mode of formation i.e., the genesis of the soil.
- A soil series may be classified into types on the basis of _____.
- Genetic system of soil classification is based entirely on _____.

- iv) Diagnostic horizons found at the surface of the soil are called _____.
- v) Manmade horizon formed during use of soil by people for long periods is called _____.
- vi) Where winters are moist and cool and summers are warm and dry, the moisture regime is called _____.
- vii) _____ are subdivision of suborders. They have been established largely on the basis of diagnostic horizons.
- viii) Soil of the order _____ are dark colored soils of grasslands
- ix) Soil order _____ represents highly leached soils with accumulation of clay in B horizon.
- x) Formation of soil order _____ is common in hot areas having stagnant marshes and swamps.
- xi) Soils developed from volcanic material and amorphous clays fall under the soil order _____.
- xii) _____ is a sub division of series based on the texture of surface soil.
- xiii) Percentage occupied by different types or series of soils in an intricate pattern in small areas shown on the map is called a _____.
- xiv) _____ is a list of defined mapping units with their symbols
- xv) The black color of soils is due to the presence of _____ compounds or clay humus complex.
- xvi) In general, red soils are derived from _____ and _____.

Answers

(i) profile (ii) soil texture (iii) soil genesis (iv) epipedons (v) anthropic epipedon (vi) xeric (vii) Great group (viii) Mollisols (ix) Ultisols (x) Histosols (xi) Andisols (xii) Soil types (xiii) soil complex (xiv) Legend (xv) titaniferous magnetite (xvi) granites & gneisses

Q. 2. Choose the correct answer:

- i) The higher categories of soil classification are comprised of a few differentiating / large number of differentiating characteristics
- ii) Soil characteristics are determined by local conditions in intrazonal soils / azonal soils
- iii) The udic moisture regime is common in the soils of humid / arid climate
- iv) Torric moisture regime occurs in arid / humid regions
- v) When the mean annual soil temperature is 22°C or higher, the soil temperature regime is called hyperthermic / thermic
- vi) Each soil great group is divided into three / many kinds of sub groups
- vii) Entisols / Aridisols are identified by the absence of distinct pedogenic horizons
- viii) Any soil with a plaggen epipedon is considered to be an Inceptisols / Vertisol
- ix) The soil mapping units are identified through profile examination / geographic studies
- x) Alluvial soils / Black soils form the largest and important soil group for crop production

- xi) Vertisol is the common soil order for the black / red soils

Answer

- (i) A few differentiating characteristics (ii) Intrazonal soils (iii) humid climate (iv) arid regions (v) hyperthermic (vi) three (vii) Entisols (viii) Inceptisol (ix) profile examination (x) Alluvial soils (xi) Black soils

Q. 3. Define the following:

- (i) Soil Taxonomy (ii) Diagnostic horizons (iii) Petroferric contact (iv) Typic subgroup (v) Catena

Q. 4. Differentiate between the following:

- (i) Residual and Transported soils (ii) Pedocals and Pedalfers (iii) Zonal soils and Azonal soils (iv) Mollic and Umbric epipedon (v) Anthropic and Plaggen epipedon (vi) Lithic and Paralithic contact (vii) Higher and Lower categories of soil classification (viii) Entisols and Inceptisols (ix) Alfisols and Spodosols

Q. 5. Write short note on the following:

- (i) Coffey's system of soil classification (ii) 7th approximation (iii) Soil order (iv) Soil families (v) Nomenclature according to soil taxonomy (vi) Extra grade formative elements

Q. 6. Comment on the following statements:

- i) Soil classification based on the productivity of the land in terms of yield per unit area is not scientific
- ii) Soil classification based on its chemical properties is not valid
- iii) Classification based on factors and processes of soil formation could not be adopted on a large scale
- iv) Different types of soils are formed under the influence of climate and vegetation
- v) Soil genesis is not ignored in Soil Taxonomy
- vi) The epipedon is not necessarily the A horizon
- vii) The name of a soil series has no pedogenic significance
- viii) Aridisols are among the most productive soils when they are irrigated and fertilized
- ix) Soils of the order Vertisols expand and contract
- x) Oxisols are commonly found in tropical to sub-tropical climates
- xi) Alfisols are naturally productive soils
- xii) There are problems in management of Histosols
- xiii) Soil phases are sub divisions of any category of soil classification in respect of slop, erosion, stoniness and salinity
- xiv) pH of peat and marshy soils is low
- xv) Marshy soils are confined to depressions

Q. 7. Answer the following in short:

- i) What are the limitations of geological classification of soils

- ii) What are the advantages of Soil Taxonomy
- iii) Enlist five epipedons
- iv) Enlist five soil moisture regimes (SMR)
- v) What is the importance of SMR and STR
- vi) What does AAWAMIHOUSE mean. Enlist it
- vii) What is the basis of differentiating suborders from given soil order
- viii) Explain with an example the concept of a Typic subgroup
- ix) Enlist soil mapping units used in soil surveys
- x) What is the practical significance of 'soil association'
- xi) What are the criteria used in nomenclature of soil family
- xii) How are red soils formed
- xiii) Enlist common orders and suborders of red soils
- xiv) Enlist chief characteristics of a laterite soil
- xv) Enlist common orders and suborders of desert soils

Q. 8 Answer the following in detail:

- i) What are the limitations of genetic system of soil classification.
- ii) What are subsurface horizon. Explain important characteristics of any four subsurface horizons.
- iii) How are soil temperature regimes (STR) expressed. Enlist important STR and their characteristics.
- v) Discuss various types of alluvial deposits in alluvial soil group. Also classify alluvial soils according to Soil Taxonomy.

□

7

Soil Survey

Soil survey is study and mapping of the soils in the field in their natural environment. It is the systematic examination, description, and classification of soils of an area. Soil surveys are conducted for preparing a scientific inventory of different soils.

Soil resource inventory provides an insight into the potentialities and limitations of the mapped area for its effective exploitation. Various soil forming factors and processes play role in evolution of soil resulting in soils with different characteristics. Based on the soil survey information and database, uses of soil vary greatly. For example, at farm level soil survey is important to select the fields to be cultivated and for which kind of cropping system, whereas in research laboratory, representative pedon are investigated in detail. In a similar way, use of soil survey and database varies at town or state level or for the development of a watershed project and so on. Thus, wise use of soils through soil survey is needed to make optimum use of soil. We must have knowledge about different soils, their morphology, characterization, behavior, kind and degree of problem and their extent and distribution on the landscape.

PURPOSE OF SOIL SURVEY

- Soil surveys are necessary to plan drainage and irrigation practices on farmlands.
- To conduct agricultural research on mapped soils so that research findings may be transferred to other areas having comparable soil-site characteristics.
- To provide information on slope, vegetation and soil characteristics up to 1 m depth (important for the planning and development of a watershed).

The purposes of soil survey are both fundamental and applied, Fundamental soil surveys provide knowledge of soils with regard to their genesis and classification. Applied aspects of soil survey help in making predictions about the behavior of different soils for agriculture, engineering and recreation aspects. Applied soil survey helps in:

- The transfer of technology under different soil conditions and management practices.
- Bringing new areas under agricultural uses.
- Demarcating disease infested and nutrient deficient areas.
- Locating and designing highways, airports and other engineering structures.
- Tax appraisal.

Soil Survey Meets the Following Objectives

- To recognize soils and define their important characteristics.
- To classify soils into mapping units, i.e. soil series, phase etc.
- To show the distribution of each class on maps.
- To furnish basic data for making interpretations as to the adaptability of the soils for agriculture or other purposes.

TYPES OF SOIL SURVEY

Depending upon the objective, method, type of base map available and the intensity of observations, four principle type of soil surveys are recognized:

- Detailed survey
- Reconnaissance survey
- Detailed reconnaissance survey
- Semi-detailed survey

Besides these, exploratory and rapid reconnaissance surveys are also recognized for preparation of small scale soil maps needed for micro level planning for agro based programs.

Detailed surveys: In a detailed soil survey soil boundaries are plotted accurately from observations on profiles throughout the area. The soils are demarcated up to lowest mapping unit, i.e. up to phases of series, as recognized by their profile characteristics. Thus, elaborate mapping is done depicting the lowest unit. Maps of scale 20.32cm = 1.609 km is used as base maps, i.e. cadastral maps on 1:5000 or 1:10000 depending upon intensity of survey. The traverse lines are on a grid pattern. It gives a comprehensive map and locates the kind and amount of geographical distribution of individual soil.

Reconnaissance survey: In a reconnaissance soil survey the boundaries are plotted from observation made at great intervals. Small-scale base maps are used. The land types, land use, texture, mottling are used as a basis for boundary delineation. The soil units delineated are of a higher category, i.e. soil associations. Maps of scale of 2.54 cm = 1.609 km or 1:10000 or 1:50000 using the toposheets of the survey of India as base maps. It gives information to precede detailed surveys and broad land use planning. A comparison between detailed and reconnaissance soil survey is presented in Table 7.1.

Detailed - Reconnaissance surveys: In the beginning, reconnaissance survey is carried out over an area. Later the selected areas (about 15%) that have better

Table 7.1. Comparison between reconnaissance and detailed survey

Items	Type of soil surveys	
	Reconnaissance	Detailed
Base maps	Toposheets	Cadastral maps
Scales average	1" = 1 mile	8" or 16" = 1 mile
Mapping units	Series Association complexes	Series type phase
Plotting of soil boundaries	At intervals	Entire length

development potentialities are surveyed in detail. It helps in understanding distribution of basic soil classes of series or families and their phases. The region of low potentialities for agriculture use are surveyed according to reconnaissance survey while areas of better agricultural potentialities are surveyed in detail.

Semi-detailed survey: It consists of a very detailed survey of some selected strips cutting across many physiographic units and soils. Thus, the soils of one unit (comprising two families) may belong to different taxa and land use recommendations are to be revised when boundaries between two soil families are delineated.

SOIL SURVEY METHODS

Soil survey methods are basically the same for any kind of prospective use. To undertake soil survey of an area, the first requisite is collection of all available information and records on soils and allied aspects and procurement of base maps. Soils are grouped according to their physical and morphological properties. Base maps are used to carry out soil surveys. It consists of (i) Panchromatic vertical aerial photographs on 1:50,000 or 1:25,000 scale. Using (i) aerial photo interpretation technique. (ii) Remote sensing technique.

Soil survey equipment

- i) Augers-screw, post hole, tube and power drilled
- ii) Munsell's color charts
- iii) Dilute hydrochloric acid
- iv) Tape, sample bags, labels
- v) Implements-Pick-axe, spade, knife, *khurpies and tagari*
- vi) Compass, Abney's level
- vii) Soil test kit

Traversing for mapping

It consists of examination, classification and mapping of soils in the field. Important soil characteristics are noted in the field. The following studies in steps provide the basis for soil mapping.

- i) The first step is reconnaissance survey of the area.(through use of aerial photography, topographical maps)
- ii) Study of the geology, climate and vegetation of the area.
- iii) Prepare a field mapping legend based on soil properties.
- iv) Carry out the fieldwork for the characteristics described (Table 7.2) as follows:
 - a) Surface and sub-surface characteristics at regular intervals, i.e. soil depth, texture, colour moisture status, depth of horizons, permeability, slope.
 - b) Observe relief erosion and land cover.
 - c) Mottles, organic matter, lime concretions, iron oxides.
- v) Establishing soil series: The following procedure may be adopted-
 - a) Identify a starting point on the cadastral map.
 - b) Move down the slope from the starting point or benchmark and observe natural vegetation, slope, erosion, soil depth, soil colour, texture by

Table 7.2. Soil depth class, Textural classes, Permeability classes, Slope classes and Soil erosion phases

<i>Soil depth class - symbol</i>	<i>Name</i>	<i>Depth range (cm)</i>
<i>d₁</i>	<i>Very shallow</i>	<i>0-7.5</i>
<i>d₂</i>	<i>Shallow</i>	<i>7.5-22.5</i>
<i>d₃</i>	<i>Moderately deep</i>	<i>22.5-45.0</i>
<i>d₄</i>	<i>Deep</i>	<i>45.0-90.0</i>
<i>d₅</i>	<i>Very deep</i>	<i>More than 90</i>
<i>Textural classes -Feel of finger</i>	<i>Texture assessment</i>	<i>Texture class and symbol</i>
<i>Very smooth</i>	<i>Fine</i>	<i>Clay (S),Silty clay (Sic), Sandy clay (SC)</i>
<i>Smooth</i>	<i>Moderately fine</i>	<i>Silty clay loam (Sicl), Clay loam (Cl)</i>
<i>Floury</i>	<i>Medium</i>	<i>Loam (l)</i>
<i>Moderately gritty</i>	<i>Moderately coarse</i>	<i>Sandy loam (SL)</i>
<i>Gritty</i>	<i>Coarse</i>	<i>Loamy sand (LS)</i>
<i>Very gritty</i>	<i>Very coarse</i>	<i>Sandy (S)</i>
<i>Permcability classes-symbol</i>	<i>Permeability class</i>	<i>Rate of flow (cm / hr)</i>
<i>1</i>	<i>Very slow</i>	<i>Less than 0.13</i>
<i>2</i>	<i>Slow</i>	<i>0.13-0.5</i>
<i>3</i>	<i>Moderately slow</i>	<i>0.5-2.0</i>
<i>4</i>	<i>Moderate</i>	<i>2.0-5.0</i>
<i>5</i>	<i>Moderately rapid</i>	<i>5.0-13.0</i>
<i>6</i>	<i>Rapid</i>	<i>13.0-25.0</i>
<i>7</i>	<i>Very rapid</i>	<i>More than 25.0</i>
<i>Slope classes -symbol</i>	<i>Slope class</i>	<i>Slope (%)</i>
<i>A</i>	<i>Nearly level</i>	<i>0-1</i>
<i>B</i>	<i>Gently sloping</i>	<i>1-3</i>
<i>C</i>	<i>Moderate sloping</i>	<i>3-5</i>
<i>D</i>	<i>Strongly sloping</i>	<i>5-10</i>
<i>E</i>	<i>Moderate steep</i>	<i>10-15</i>
<i>F</i>	<i>Steep</i>	<i>15-25</i>
<i>G</i>	<i>Very steep</i>	<i>25-33</i>
<i>H</i>	<i>Very, very steep</i>	<i>More than 33</i>
<i>Soil erosion phases-symbol</i>	<i>Erosion phase</i>	<i>Characteristics</i>
<i>e₁</i>	<i>No apparent or slight (sheet) within a horizon</i>	<i>0-25% top soil or original plough layer removed</i>
<i>e₂</i>	<i>Moderate (sheet and rill)</i>	<i>25-75% top soil removed</i>
<i>e₃</i>	<i>Severe (sheet, rill and small gullies)</i>	<i>75-100% top soil and up to 25% sub-soil removed</i>
<i>e₄</i>	<i>Very severe (shallow gullies)</i>	<i>Gullied land</i>
<i>e₅</i>	<i>Very, very severe (big gullies)</i>	<i>Very severely gullied land or sand dunes</i>

feeling the soil, pH and carbonate using dilute HCl at an interval of about 200 meters. [An augur is carried to bore a hole for collection of sample (if necessary) and to note subsoil characteristics].

- c) A number of soil characteristics may change. Follow the line of change in soil properties and demarcate it. This forms boundary between soil units A and B. Again move down the slope till again soil characteristic change.
- d) Follow the line of change of soil properties between soil units B and C and demarcate it on the field.
- e) In a similar way, find out and demarcate the boundaries between soil units C and D, D and E and so on as shown in Fig. 7.1.
- f) Then dig profiles in each of the soil units. The number of profiles varies with the area of soil units. If the characteristics of the profile in soil units A, B, C, D and E are different than the soil units A, B, C, D and E become soil series A, B, C, D and E.
- g) A survey report is written describing the soil series.

The following pattern for survey may be adopted depending on the need of survey.

Grid survey: The traverse lines are located on a grid pattern. The number of observations per cm^2 on the map is independent of the scale. Generally four to five observations per hectare are recommended. This method is adopted to establish correlation between soils and aerial photo units.

Free survey: Free survey is conducted for check up and confirmation of the established soil - physiographic relationship. Physiography as observed by aerial

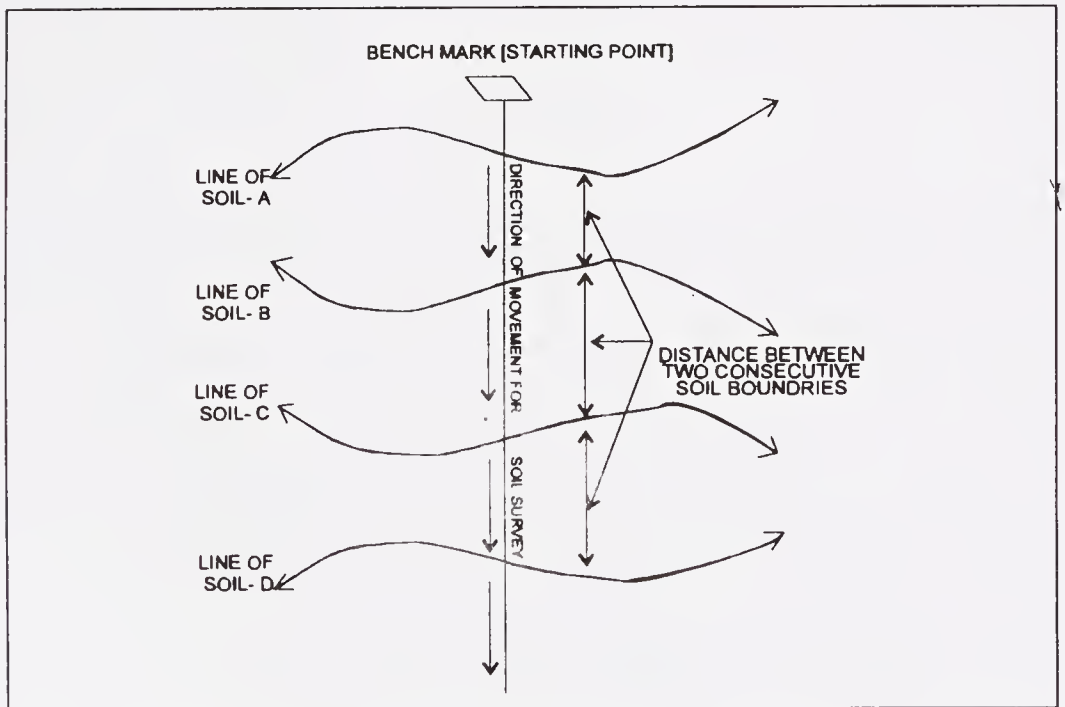


Fig. 7.8. The method of detailed soil survey [Lines of soil A,B,C,D indicate the change of soil characteristics]

photo and other surface features such as soil colour, vegetation and land use are indicative of differences in soil characteristics. Soils of an area are grouped into soil series based on differences in physiography, drainage, parent material and profile development. Soil mapping is based on topography, vegetation and surface soil colors. Scientists have made soil surveys and characterized soils in areas around the world. Areas dominated by specific soil orders and suborders are delineated on the maps using map symbols. Keys have been developed to help scientists determine which soil order, suborder, great group etc is present in a given field site. This key is based strictly on soil properties that can be measured by physical and chemical means.

TECHNOLOGIES FOR MAPPING

- i) It involves the use of aerial photographs.
- ii) Video image analysis (VIA) is used to examine aerial photographs. It distinguishes shades of gray. The color differences are related to soil and vegetation.
- iii) Ground penetrating radar (GPR): High frequency impulses of energy are transmitted into the soil. When the impulse strikes between soil particles, energy is reflected back to the surface. This reflected energy is measured and displayed on a recorder. Salt content, moisture and type of clay affect its use.

USES OF SOIL SURVEYS

- i) It serves in better utilization of land resources.
- ii) They form basis for all soil research.
- iii) They form basis for planning, irrigation, and drainage and erosion control.
- iv) Soil survey can be used to determine land suitability for agricultural and other purposes.
- v) Soil survey is of practical value in land capability classification.

References and Suggested Readings

Miller, R.H. and Donahue, R.L. (1997). *Soils in Our Environment*. Prentice Hall of India, New Delhi.

Soil Survey Manual (1995). Soil Survey Division Staff U.S.D.A. Scientific Publishers, Jodhpur.

QUESTIONS

Q. 1. Fill in the blanks

- i) In reconnaissance soil surveys, the soil units delineated are of a higher category i.e., _____.
- ii) In _____ surveys toposheets of the survey are used as base maps.
- iii) _____ survey gives information to precede detailed surveys and broad level planning.

- iv) _____ survey is adopted to establish a correlation between soils and aerial units.
- v) _____ is used to examine aerial photographs.

Answers: (i) soil associations (ii) reconnaissance (iii) reconnaissance (iv) Grid (v) Video Image Analysis.

Q. 2. Choose the correct answers

- i) In detailed soil surveys / reconnaissance surveys elaborate mapping is done depicting the lowest category of mapping units.
- ii) In reconnaissance / detailed surveys small scale base maps are used.
- iii) Free surveys / grid surveys are conducted for check up and confirmation of the established soil-physiographic relationships.
- iv) Soil surveys are necessary / not necessary for the planning and development of a watershed.
- v) Bringing new areas under agricultural uses is a function of applied soil survey/ fundamental soil survey.

Answers

(i) detailed soil surveys (ii) reconnaissance (iii) free surveys (iv) necessary (v) applied soil survey.

Q. 3. Define the following

(i.) Soil survey (ii) Ground penetrating radar (GPR) (iii) Grid survey

Q. 4. Differentiate between the following

- i) Fundamental and applied soil surveys (ii) Detailed and semi-detailed surveys
- iii) Grid survey and free survey

Q. 5. Write short notes on the following

(i) Soil resource inventory (ii) Detailed reconnaissance survey (iii) Uses of soil surveys

Q. 6. Give comments on the following statements

- i) Soil surveys are conducted for preparing a scientific inventory of different soils
- ii) Based on the soil survey information and database, uses of soil survey vary greatly.
- iii) Physiography is an indicative of differences in soil characteristics.
- iv) Soil survey is of practical value in land capability classification.
- v) Keys have been developed to help scientists determine which soil order, suborder, great group etc. is present in a given field site.

Q. 7. Answer the following in short

- i) What are the major information's one should know to make best use of soil?
- ii) How are applied soil surveys useful?
- iii) Enlist objectives of soil surveys?

- iv) How should one proceed for soil surveys?
- v) Enlist equipment commonly used in soil surveys
- vi) What is the basis of classification of soil surveys?
- vii) Enlist different type of soil surveys?

Q. 8. Answer the following in detail

- i) Give a detailed stepwise account for conducting survey of an area to be utilized for agricultural purposes
- ii) Explain different patterns to be adopted for conducting surveys

Q. 9. Give diagrammatic view of the following

- i) Method of establishing a soil series.



Land Capability Classification

LAND is utilized for developmental works on the basis of information received from soil survey reports because it is not always possible to conduct field trials on individual soil mapping unit. Soil should be given due consideration before proceeding for any developmental work for sustainable agricultural production. For example, use of heavy machinery on shallow soils may result in exposure of poor coarse textured calcareous soils. Similarly, fine textured soils are more susceptible to waterlogging, sodicity and nutrient imbalance whereas coarse textured soils are poor in their water holding capacity and nutrient content. Land, if interpreted suitably in terms of their capability will help policy makers optimum use of the soil and make land use recommendations. This system is helpful in identifying practices that can minimize soil erosion.

CLASSIFICATION

Land capability is an evaluation of land according to its limitations for agricultural use. The grouping of soils is done primarily on the basis of their ability to produce plants without deterioration for a long time. Land capability classification is based on the following factors:

- Inherent soil characteristics like nature of parent material, colour, texture, structure, consistency, permeability, depth of soil, pH.
- External land features like slope and erosion and
- Environmental factors that limit the land use like salinity and alkalinity, high water table, hard clay pan, stoniness. All these factors affect land capability.

The land capability classification is done at three levels- classes, subclasses and units. It is based on the capability and limitations of every hectare of land. These classes are numbered from I to VIII. Soils having greatest capabilities for response to management and least limitations are included in Class I, those with least capabilities and greatest limitations are placed in Class VIII.

CAPABILITY CLASSES, SUB-CLASSES AND CAPABILITY UNITS

Capability Classes

Land capability class indicates the degree of total limitations on the land use. There are eight classes in the highest category of the land-use capability system, numbered from I to VIII. Class I to Class IV include land suited for cultivation and can be used for other purposes. Class V to VIII includes land that cannot be cultivated in their present state under normal management. These should be

maintained under natural vegetation of forests or grasses. Climate has a major role on the capability.

Effects of Climate

Climate affects the capability of the land to produce field crops, pasture or forest crops. In general greater the amount of rainfall more conducive it is for production. The effect of climate when considered in isolation and the soil characteristics and other land features are favourable, are tabulated below:

Type of climate	Land capability class
(i) Humid with well-distributed rainfall	Class I onwards
(ii) Humid climate with occasional dry spells	Class II onwards
(iii) Sub-humid, crop yields frequently reduced by droughts	Class II to III onwards
(iv) Semi-arid	Class III to IV onwards
(v) Arid	Class IV onwards

A brief description of soil capability classes is presented here:

Class I : It is a very good land and can be cultivated safely with good farming branches. The soils are deep, well drained and level. These lands are either naturally fertile or have characteristic that encourage good response to application of fertilizers. These lands are free from hazards. Thus Class I land does not have any subclass.

Class II : It is a good land. These soils require moderate conservation practices and choice of crops is reduced. Their use may be limited by one or more factors like moderate erosion, inadequate soil depth, slightly saline and alkali soils and somewhat restricted drainage. Thus management practices like terracing, strip cropping, contour tillage, grasses and legumes may be required. Use of manure and fertilizer, disposal of excess water from the lands through waterways, suitable mulching or the right combination of practices should be adopted depending on the problem.

Class III : It is a moderately good land. These soils have severe limitations that reduce choice of crops or require special soil conservation practices or both. Limitations as indicated in Class II are further intensified. Strip cropping in narrow strips, long crop rotation, terraces and outlets, diversion ditches, waterways fortified with vegetation, contour tillage, and cover crops and mulching are to be used.

Class IV : There are severe limitations on the choice of crops in these soils. These lands are suitable only for occasional or limited cultivation. This needs careful management. The hazards are more serious than in the case of Class III lands. The use of such lands for agriculture is very restricted and is best maintained by perennial vegetation. Maintenance of such lands needs special measures, which are difficult and costly.

Class V : Class V lands have more or less the same characteristic as Class I land except for one or more limitations of stoniness or wetness or adverse climatic conditions. They are not suitable for cultivation because of one or more factors

like excessive wetness and susceptibility to flooding for a very long duration. The soils can be used safely for grazing, forestry and wild life without erosion hazards. Their limitations include frequent stream overflow, short growing season, stony or rocky soils and drainage is not feasible. These lands do not need special measures except for woodland management practices like prevention of fire.

Class VI : These, soils have extreme limitations, which restrict their use to pasture or wildlife. Limitations are more rigid than Class V. It is too steep, subject to erosion, shallow, wet, dry but with careful management can be used either for grazing or forestry. Contour furrows, ridges, diversions are useful on some sites to store moisture in the soil by checking or diversifying the water.

Class VII : These soils have severe limitations, which restrict their use to grazing or wildlife. The limitations do not permit pasture improvement. It can be used for grazing or forestry if carefully handled.

Class VIII : These soils should not be used for any kind of commercial production. Land use is restricted to recreation, wildlife or aesthetic purposes.

The criteria used to group soils into different capability classes are qualitative and work well for new areas being brought under agricultural use. It may not be satisfactory for traditionally cultivated areas. Therefore it needs quantification. An attempt made to semi-quantify the criteria with respect to each capability class by Sehgal (1996) is presented in Table 8.1

Capability Sub-Classes

These are subdivisions of capability classes. The sub-classes explain the reasons for the limitations of intensive crop production. This is based on four dominating limitations. Thus, there are four land capability sub-classes. These limitations alongwith their limitations symbol use are as follows:

(Climate): Climate limitations like low rainfall, very high and low temperature, too cold or too dry.

(Erosion): Risk of erosion or degree of damage due to erosion.

(Soil hazard): Root zone limitation, moisture holding capacity, rapid drainage, salinity, stoniness or other land features which would effect tillage operation and root zone of crops.

(Wetness): Problems of wetness, drainage or overflow.

Adding limitation symbol to the capability class number designates sub-classes. For example, IIc or IIIe, indicating that it is in Class II because of climatic limitations or in Class III because of risks of erosion. There are no sub-Classes in Class I.

Capability Units

Land capability unit is the smallest and last category in the land capability classification system. A capability unit consists of soil, which are nearly uniform in their characteristics, potentialities and limitations and require fairly similar conservation treatments and management practices. Adding numbers to the sub-classes forms land capability units. For example, capability units IIc 1, IIIc 2 would represent several Class II soils with climate hazards arising from different causes. Some might be because of erosion due to water or wind; still others might be because of factors like overflow or too hot or cold conditions.

Table 8.1. Land capability classification - quantification of the criteria

Characteristics	Class I	Class II	Class III	Class IV	Class V	Class VI	Class VII	Class VIII
<i>Topography (t)</i>								
Slope (%)	0-1	1-3	3-8	8-15	Upto 3	15-35	severe	35-50
Erosion	nil	sight	moderate	severe	nil	v.severe	>50	
<i>Wetness (w)</i>								
Flooding	Nil (Fo)	nil (Fo)	nil to slight (F/F 2)	Slight to mod. (F3)	Mod.to severe (FO/F 3)	Nil to severe severe (FO/F4)	nil to very excessive	— excessive
Drainage	Well	mod.well	imperfect	poor	v.poor	—	—	—
Permeability	Moderate	mod.rapid	rapid.slow	v.rapid.very slow	—			
Infiltration rate (cm/hr)	2-3.5	1-2.0	0.5-1.0	<0.5	2.0			
		3.0-5.0	5.0-10.0	>10.0				
<i>Physical Soil Conditions (s)</i>								
Surface texture	Loan	sil & cl	sl & c	Scl	s,c (m)	1s-cl	1s,s,c	1s,s,c(m)
Surface coarse fragments (vol.%)	1-3	3-15	15-40	40-70	15-75	75+		
Surface								
Stoniness(%)	<1	1-3	3-5	5-8	8-15	15-40	40-75	>75
Subsurface coarse								
Fragments(%)	<15	<15	15-35	35-50	50-75	50-75	50-75	>75
Soil depth (cm)	>150	150-100	100-50	Salic(Z)/	—	25-10	25-10	<10
Profile development	Cambio/ Argilic hor. A-(B)=C	A-B-C	Stratified A-C;A-B-C	Classic(K) hor. A-Bz-C/A-Bk-C	Az-C;A-Bz-C-C	Gypsic(y) h or. A-Cy	A-C (Stony)	A-C (boundary)
<i>Fertility (f)</i>								
CEC(Cmol(p) kg-1)	40-16	16-12	16-12	—	—	—	—	—
Base saturation (%)	80+	80+	80-50	50-35	50-35	35-15	<15	—
O.C.(0-15 cm) (%)	>1.0	0.75-1.0	0.5-0.75	<0.5	<0.5	—	—	—
Salinity EC(dS m ⁻¹)	<1.0	1-2	2-4	4-8	8-15	15-35	35-50	>50
Gypsum (%)	0.3-2.0	2-5	5-10	10-15	15-25	>25	—	—

Land Capability Maps, Coding and Color Notation in Classification

Land capability maps are prepared by interpreting the soil survey data. Different land capability classes, sub-classes are differentiated on the basis of major soil characteristics and land features. Each of the land capability class and sub-class are coded and given standard color, after demarcating the area of the class. Coding is generally done with the help of the soil survey data collected during soil survey after locating the site on the map. Out of all the soil characteristics and associated land features, the most important ones considered for classification are effective depth, texture of top soil, permeability of top soil and that of substratum, slope and erosion hazard. The first four are written in the numerator and the remaining two in the denominator along with the name of the soil series. (From Watershed management by V.V. Dhruva Narayan and others, 1997)

Depth × texture of × Permeability of × Permeability of
 the top soil the top soil substratum

Color Notation

The capability Class and color notation are given below:

I	Light green	II	Yellow	III	Red	IV	Blue
V	Dark green	VI	Orange	VII	Brown	VIII	Purple

Capability Index (Ci)

In order to quantify the irrigability approach, Cys (1976) proposed a parametric approach for evaluating the suitability of soil for irrigation. This is based on 7 parameters of soils, considered most imperative. They are soil texture, soil depth, CaCO₃ status, gypsum status, salinity / alkalinity status, drainage condition and topography.

References and Suggested Readings

- Cys, C. and Sehgal, J. (1996). *Pedology Concepts and Applications*, pp. 257–59. Kalyani Publishers.
- Dhruva Narayana, Sastry, G. and Patnaik, U.S. (1997). *Watershed Management*. ICAR, New Delhi.
- Sehgal, J (1996). *Pedology Concepts and Applications*. Kalyani Publishers, Ludhiana.

QUESTIONS

Q. 1. Fill in the blanks

- All the soils within the land capability _____ are only similar in degree of limitation in soil use.
- The land capability class is further divided into _____ depending upon the kind of limitation for its use.
- _____ land is suitable only for occasional or limited cultivation.
- Land use for Class VIII land is restricted to _____.

Answers

- (i) Class (ii) Sub-Class (iii) Class IV (iv) recreation, wild life or aesthetic purposes

Q. 2. Choose the correct answer

- i) Land capability Class / sub-Class indicates the degree of the total limitations on the land use.
- ii) Class V to VIII land should be maintained under natural vegetation of forests and grasses / should be used for cultivation.
- iii) Class III / Class II land is categorized as a moderately good land.
- iv) Pasture improvement is not recommended / recommended for Class VII land.

Answers

(i) Class (ii) natural vegetation of forests and grasses (iii) Class III (iv) not recommended.

Q. 3. Define the following

- (i) Land capability classification (ii) Capability units.

Q. 4. Differentiate between the following

- (i) Land suitable for cultivation and land unsuited for cultivation.
- (ii) Management practices of Class V and Class VI land.

Q. 5. Write short notes on the following

- (i) Significance of land capability classification (ii) Color notations in land capability classes.

Q. 6. Give comment on the following statements

- i) Land if interpreted suitably in terms of their capability will help policy maker's optimum use of the soil and make land use recommendations.
- ii) In general, with the decrease of the effective rainfall, the capability Class also decreases.
- iii) Class I land does not have any sub-class.
- iv) Maintenance of Class IV lands needs special measures, which are very difficult and costly.
- v) Class V land have more or less some characteristics as Class I.

Q. 7. Answer the following in short

- i) Enlist factors determining land capability classification.
- ii) What are different land capability sub-classes.
- iii) What is meant by soil hazard as a sub-classes of land capability classification.
- iv) What different management practices may be required for Class II land.
- v) How are soil series named in a land capability classification.

Q. 8. Answer the following in detail

- i) What do you understand by land use capability classification? Describe characteristics of each capability class of soil.



SECTION B

Soil Physics

Soil Physical Properties

Soil Physical Properties

Soils are composed of solids, liquids and gases mixed together in variable proportions. The relative amount of air and water present depend on how tightly the solid particles are packed together. Physical properties have great significance because air and water relations are determined largely by the physical make up of the soil horizons. Soil colour, soil texture, soil structure, bulk density and particle density, plasticity, adhesion, cohesion and flocculation are important physical properties of soils. These properties determine the availability of oxygen in soils, the mobility of water into or through soils, and the ease of root penetration.

SOIL COLOUR, ITS SIGNIFICANCE AND DETERMINATION

Colour is one of the most noticeable characteristics of a soil. The importance of soil colour can be recognized because of following contributions.

- i) It is an important criterion in description and classification of soils.
- ii) Colour of the soil has relevance to soil constituents.
- iii) Soil colour tells about soil conditions.
- iv) It gives useful indication of soil forming processes.

The Significance of Soil Colour can be Summarized in the Following Discussion

- Humus is black in colour. Thus in general a black coloured soil may be rich in humus as in temperate climates. However in some cases the black colour of soils may be due to titaniferous and magnetite compounds or clay humus complexes. Colour also indicates the degree of oxidation of iron and manganese compounds.
- Oxides of iron and manganese impart red, brown and yellow colours, depending on the oxidation status and hydration of these compounds. The yellow colour in soils is due to oxides of iron ($2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$). Brighter colours like red or reddish brown are characteristic of well-oxidized conditions. Under reducing conditions bluish-grey colour occur. The iron compounds in wetter soils accumulate in spots called mottles that consist of spots of one colour in the background of another colour. This is due to variation in the Oxidation State of iron being present both as ferrous and ferric forms.
- Brown colour is due to a mixture of organic matter and iron oxides.
- Quartz is white, or lighter in colour and clay is darker. Thus lighter coloured soils are richer in sand than the darker soils. Hence darker coloured soils are richer in clay and more fertile than the lighter coloured soil.

- Colour of the soil may be inherited from its parent material for example red soils developed from red sandstone. This is called lithochromic colour. Sometimes, soil may acquire colour as a result of soil forming processes. This is called genetic or acquired or pedochromic colour i.e. red soils developed from granite, gneiss or schist. In young soils, the parent material influences the colour. With increasing stage of soil development following increased temperature and rainfall, the soil colour tend to become brownish or reddish rather than greyish.
- In places where the normal soils have red colour, the well-developed red colour of soils is due to intensive weathering.
- Poorly drained soils have mottled shades of grey, brown and yellow shades, within the zone of fluctuation of water table.
- Soil colours are grayish in cold, humid region and are modified towards black or brown according to the amount and nature of organic matter, iron hydroxide and drainage conditions. In warm humid regions, soils are red because of intensive weathering and release iron oxides or hydroxides under well-drained conditions.
- Soil colour has a direct bearing on soil temperature. Darker soils absorb heat more readily and warm up quickly. But this is not always true as these soils are rich in organic matter and hold more water, thus specific heat of soil is raised. Consequently, such soils though darker in colour, may not warm up quickly.

Determination of Soil Colour

Soil colour is determined by Munsell's soil colour chart, which may be obtained from the address mentioned below:

**Munsell colour, Macbeth A Division of Kollmorgen Corporation
2441 North Calvert Street, Baltimore, Maryland 21218 USA**

Soil colour is expressed by the Munsell colour notations, which comprise of three variables:

Hue: is the dominant spectral colour (rainbow): It is related to dominant wavelength of light. The hue notation of a colour indicates its relation to Red, Yellow, Green, Blue and Purple. The symbol for hue is the letter abbreviation of the colour of the rainbow (R for red, YR for yellow-red, Y for yellow) preceded by numbers from 0 to 10. The hue becomes more yellow and less red as the number increase.

Value: is the lightness or darkness of the dominant spectral colour:. The notation for value consists of numbers from 0, for absolute black, to 10 for absolute white. Thus a colour value of 5 is visually midway between absolute white and absolute black. One of value 6 is slightly less dark.

Chroma: is the purity of the dominant colour: The notation for chroma consists of numbers beginning at 0 for greys and increasing at equal intervals to a maximum of about 20 (near really approached in soil).

All the three variables have been arranged in a note book called Munsells soil colour charts. The practice is to match colour of a soil with that in Munsell



Fig 9.1. A page from Munsell's soil colour charts

colour charts. All, the colour chips shown in each page of the Munsell colour chart are of the same hue which is written at the top right hand corner of the page as shown in Fig 9.1. Vertically, their value increases (indicated in the left column of the chart). The colours become successive lighter from the bottom of the card to the top by visually equal steps, their value increases. Horizontally, their chroma increases (indicated by the horizontal scale across the bottom of the chart). On opposite page corresponding English name of the soil colour is mentioned. Soil colour changes with the moisture content. In dry and moist samples of the same soil, there may be a difference of about $\frac{1}{2}$ to 3 units in value and from $-\frac{1}{2}$ to +2 in chroma but the hue remains unchanged. The moist colour has darker shades.

In writing the Munsell notation, the order is hue, value, chroma with a space between the hue letter and the succeeding value number, and a virgule between the two numbers for value and chroma. If expression beyond the whole numbers is desired, decimals are always used, never fractions. Thus the notation for a colour of hue 5YR, value 5, chroma 6 is 5YR 5/6, a yellowish red. The notation of a colour midway between the 5YR 5/6 and 5YR 6/6 chips is 5YR 5.5/6. Since colour determinations cannot be made precisely in the field expression of colour should ordinarily be to the nearest colour chip. The probability of having a perfect matching of the sample colour is less than one in one hundred. It should be evident, however which colours the sample lies between, and which is the closest match.

SOIL TEXTURE

Soil texture refers to the percentage by weight of each of the three-particle size fraction sand, silt and clay. The texture of a soil is an almost permanent character, as texture does not change over a long period of time. Texture is an important soil characteristic because it determines water intake rates, water storage in the soil, the ease of tillage operations and the aeration.

Particles larger than 2mm are excluded from soil texture determinations as they make little or no contribution to basic soil properties such as the water holding capacity and capacity to store and supply plant nutrients. However, in classifying and mapping of soils, the names of the larger fragments are attached to and precede textural name of the soil, for example, stony sandy loam.

Classification of Soil Separates

The groups of soil particles made according to their size are called soil separates (sand, silt and clay). Soil separates have been classified as follows:

International system: suggested by Atterberg (1912)

Soil separate	Diameter (mm)
Coarse sand	2-0.2 mm
Fine sand	0.2–0.02 mm
Silt	0.02–0.002 mm
Clay	less than 0.002 mm

United States Department of Agriculture (USDA) system

Soil separate	Diameter (mm)
Very coarse sand	2.0–1.0 mm
Coarse sand	1.0–0.5 mm
Medium sand	0.5–0.25 mm
Fine sand	0.25–0.10 mm
Very fine sand	0.10–0.05 mm
Silt	0.05–0.002 mm
Clay	less than 0.002 mm

PROPERTIES OF SOIL SEPARATES (Mechanical separates)

Sand: Sand is composed of weathered grains of quartz [0.2–0.02 millimeters (mm) in diameter]. They are gritty to touch. Sand creates pores and thus improves infiltration and aeration. Sand is chemically inactive and constitutes the framework or skeleton of the soil mass.

Silt: Silt particles (0.02–0.002 mm), are powdery when dry and even when wet are not sticky. Silt has the ability to hold large amounts of water in a form plant can use. Fine sand feels silky, silt gives smooth and non-sticky feel.

Clay: The smallest mineral particles are the clay (<0.002 mm), which form a sticky mass when wet and aggregate into hard clods when dry. Clay has a high surface area per unit mass because of small size of the individual particles. Since the adsorption of water, nutrients, attraction of particles for each other are all surface phenomena, clay plays a significant role in determining these soil properties. Clays being secondary products of chemical weathering are very active fractions of soil.

Loam Soil

Loam soils are highly desirable for most uses. Loam exhibits approximately equal properties of sand, silt and clay. They have enough clay to store adequate amounts of water and plant nutrients for optimum plant growth. They contain enough silt to hold sufficient available water for plants, to gradually form more clay and to release fresh plant nutrients by weathering. Clay content is not much as to cause poor aeration or to make working with them difficult. A soil containing between 7 to 27% clay and approximately equal amount of silt and sand has a loam texture.

Soil Textural Classes

Based on the relative proportion of each of the three-soil separates- sand silt and clay, twelve textural classes have been identified. Textural classes along with their percentage of sand silt and clay have been presented in Table 9.1

Surface Area Effect

Surface area is primarily a function of the size of particles. The ratio of total

Table 9.1. Twelve textural classes and their percentage of sand, silt and clay

Group	Textural class	Range in per cent		
		Sand	Silt	Clay
Coarse textured	Sand	85–100	0–15	0–10
	Loamy sand	70–90	0–30	0–15
	Sandy loam	43–80	0–50	0–20
Moderately textured	Loam	23–52	28–50	7–27
	Silt loam	0–50	50–88	0–27
	Silt	0–20	80–100	0–12
	Sandy clay loam	45–85	0–28	20–35
Fine textured	Clay loam	20–45	15–53	27–40
	Silty clay loam	0–20	40–73	27–40
	Sandy clay	45–65	0–20	35–45
	Silty clay	0–20	40–60	40–60
	Clay	0–45	0–40	40–100

area to total mass is called specific surface. An idea of the changes may be obtained by the consideration of increase in area of a cube, if it is divided into its smaller portions. The surface area of smaller particles obtained from the same mass increases inversely with the reduction of size. The smaller the radius, the higher is the specific surface area. As regards the number of particles per unit weight or volume of soils, it is not possible to determine it with accuracy. However, by assuming that all particles are spherical and by reducing them to their average diameter, a rough estimate can be made of the number of particles per gram of soil from the formula:

$$N = \frac{\text{Weight of soil (g)}}{\text{Weight of individual soil particle}} \\ = \frac{1}{6} \pi D^3 \times 2.65$$

Where N = number of particles per g

D = mean effective diameter of the particles in cm

2.65 = average particle density of soil

Calculated this way, the average number of particle per/g of fine sand would be 1.7 million, that of silt 35 million, and of clay 50,000 million.

DETERMINATION OF SOIL TEXTURE

The determination of the percentage of soil texture can be done in two ways.

Feel Methods

A simple test, which can be done on site in the field. It is useful in soil

survey and land classifications. Moisten a small amount of soil to medium moisture level. Note any grittiness that indicates sand or the stickiness of clay. Mould the sample into a ½" ball and try to lightly squeeze the ball. If the ball breaks at the slightest pressure, it is sand or coarse sandy loam. Sand feels gritty, and its particles can be easily seen with the naked eye. Silt feels smooth like flour or talcum powder when dry and slightly plastic or sticky when wet. Clay feels sticky and plastic and exhibit stickiness when wet and hard under dry conditions. If ribbons are formed from wet soil mass, the length of the ribbon also serves as a guideline for textural group. Longer ribbons are formed from soils containing more clay. This is a common method used by soil surveyors.

Mechanical Analysis or Particles Size Analysis

The process of determining the amounts of individual soil separates (in percentage) below 2 millimeters in diameter, that is sand silt and clay, is called mechanical analysis. This is also known as particle size analysis as it determines various soil separates, i.e. sand, silt and clay. It is based on Stokes's law. Two methods are based on this principle: i]. Hydrometer method (Bouyoucos 1927) ii]. International pipette method.

Hydrometer Method

It is based on the principle that there is a continuous reduction of the density of the soil suspension with time at the rate the particles fall below the level of hydrometer. The density of the suspension progressively increases downward. By knowing the density of the suspension with calibrated hydrometer after known times different fractions are calculated. Correction factor is incorporated for temperature, i.e. for any change other than 67°F, add or subtract 0.2 in the hydrometer reading for % suspension.

International Pipette Method

The sand separates are determined by sieving and the silt and clay separates are determined by their settling rates in water. The effect of organic matter and calcium carbonate (since they bind soil particles) is removed by treating soil with hydrogen peroxide and HCl respectively. After the time lapses for silt + clay and clay (from the mechanical analysis chart), soil water suspension is drawn. Suspension is dried and amount of silt and clay are determined.

STOKES'S LAW

G.G. Stoke determined the relationship between the size of particles and their rate of falling in a liquid medium in 1851. He stated that "the resistance offered by a liquid medium against the fall of particles down the same liquid medium, varies with the radius of the particles". According to the formula

$$V = \frac{2 (d_p - d) g r^2}{9 \eta}$$

$$\text{Since } V = \frac{H}{T} = \frac{2(dp-d)gr^2}{9\eta} = \frac{2(dp-d)gD^2}{9\eta \times 4} = \frac{(dp-d)gD^2}{18\eta}$$

$$\text{therefore } t = \frac{18\eta h}{(dp-d)D^2}$$

Where V = velocity of fall of particles in cm/sec.

r = radius of the particles in cm.

g = acceleration due to gravity cm/sec, 980 cm/sec.

D = diameter of particle in cm.

dp = density of particles in g/cc, about 2.6g/cc.

d = density of the medium in g/cc, about 1g/cm³

h = height of fall of particles in cm/sec.

η = viscosity of the solution, (g/cc/sec), about 0.010 poise at 20°C.

t = time taken by particles to fall

The value of t increases when the value of D decreases. Therefore, as the size of the particles is decreased, the time taken by them to fall down the same depth increases.

Assumptions in Stokes's Law

- It assumes that smooth rigid spheres are settling. Soil particles may not be smooth over their surfaces. Also, the particles are not spherical.
- The particles must be large in comparison to liquid molecules so that brownian movement will not affect the fall.

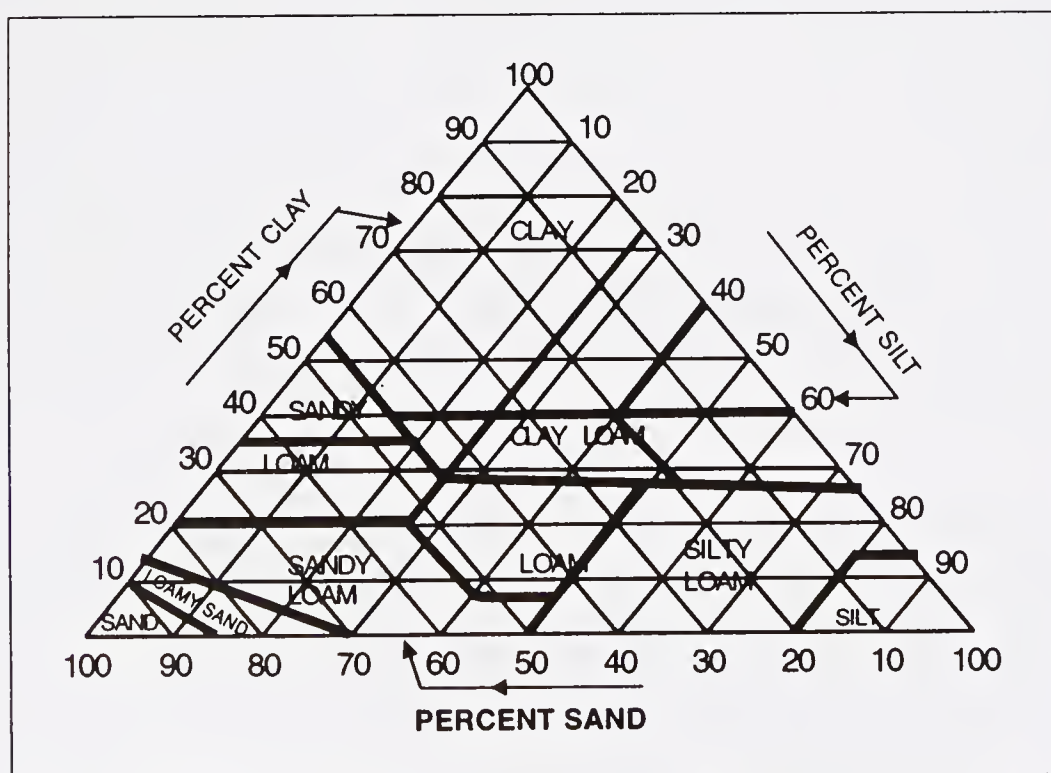


Fig 9.2. Textural Triangular Diagram (USDA System for Textural Designations)

- The extent of the liquid must be more in comparison with the size of the particles.
- The velocity of fall must not exceed a certain critical value so that the viscosity of the liquid remains the only resistance to the fall of the particle. Particles larger than silt cannot be separated accurately by the use of Stokes's law.

Use of Textural Triangle Diagram

The textural triangle is used to determine the soil textural name as given in Fig. 9.2 and 9.3 (USDA and International systems of textural classification respectively). The triangle is divided into twelve compartments containing all possible proportions of sand, silt and clay. This can be prepared as follows:

- Draw an equilateral triangle of 10 cm each side. Divide it in to equal parts and mark 0,10,20 and so on up to 100.
- Name the sides of triangle. Left side (clay), right side (silt) and bottom side (sand) as shown in the figure, the numbers 0,10,20 to 100 increasing in a clockwise direction.
- Locate the points as follows: (as shown in the Fig. 9.2 and 9.3)
 - 55 on the clay line and 45 on the sand line
 - 60 on the silt line and 40 on the clay line.
 - 73 on the silt line and 27 on the clay side and draw a line through them till they intersect the 55-45 line.
 - 28 on the silt side and 72 on the sand side.
 - 20 on the clay side and 80 on the silt side, it intersects 28-72 line.
 - 48 on the clay side and 52 on the sand side.
 - 7 on the clay side and 93 on the silt side.
 - It intersects 48-52 line.

Draw Following Lines Parallel to the Clay Sides

- 50 on the sand side till it intersects 73-27 line.
- 40 on the silt side till intersects 60-40 line
- 20 on the sand side through the point 88 on silt line till they intersect.
 - Join the points 70 on the sand line and 15 on the clay line.
 - Join 85 on the sand line and 15 on the clay line.
 - Erase the unnecessary portions of different lines.

To Locate the Textural Name

- Locate the percentage of silt and project towards base line (sand line).
- Locate the percentage of sand and project towards clay line.
- The point at which the points intersect is the textural name.
- In case, the points representing the texture of a soil sample fall exactly on the line between two texture names, the name of the finer fraction is considered.
- In case, the points representing the texture of a soil sample fall exactly on the line between two texture names, the name of the finer fraction is considered.

Percentage of sand, silt and clay in the major soil textural classes. To use the diagram, locate the percentage of clay first and project inward as shown by the arrow. Do likewise for the percent silt (or sand). The point at which the two projections cross will identify the class name.

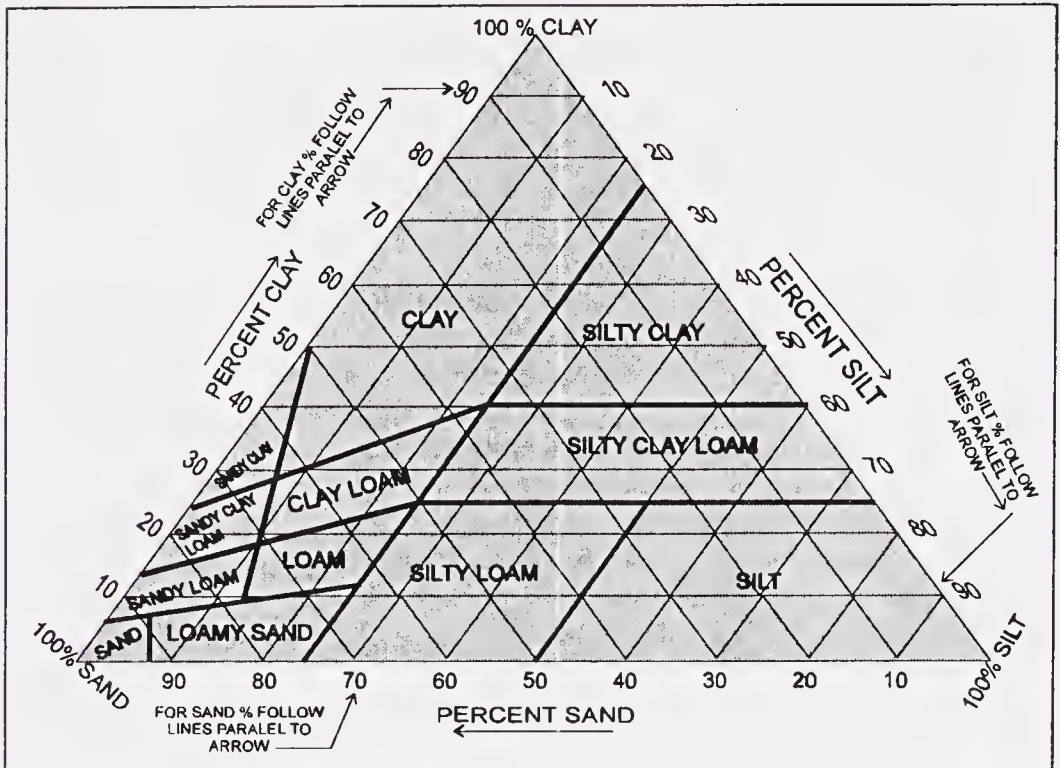


Fig. 9.3. Textural Triangular Diagram (International System for Textural Designations).

Example: Find out the texture of the soil of the following composition:
Mixture of gravel, cobble and stone = 50 g, Sand = 60 g, Silt = 25 g.,

Clay = 15 g., Total=150 g.

$$\text{Percentage of Gravel, Cobble and stones} = \frac{50 \times 100}{150} = 33.3$$

Weight of the soil excluding gravel, cobble and stones = $150 - 50 = 100$ g

$$\text{Per cent of sand in the soil excluding gravel} = \frac{60 \times 100}{100} = 60$$

$$\text{Per cent of Silt in the soil excluding gravel} = \frac{25 \times 100}{100} = 25$$

$$\text{Per cent of clay in the soil excluding gravel} = \frac{15 \times 100}{100} = 15$$

Locate the per cent of clay and project toward in the triangular textural diagram, locate the per cent of silt and locate towards base line, and per cent sand towards clay line. Note the point of intersection. The texture of the given soil is sandy clay.

IMPORTANCE OF SOIL TEXTURE

The texture of a soil is one of the fundamental considerations in soil classification. Textural analysis also indicates the weathering stage to some extent. Textural class name is suggestive of many soil properties that have its bearing on its management and productivity. The soil texture controls water contents, water intake rates, aeration, root penetration and some chemical properties. Each type of particle present makes its contribution to the nature of the soils a whole.

- Clays with organic matter stores water and nutrients, helps to bind particles into aggregates. Sand serves as a skeleton to the soil and helps to make soil permeable and well aerated.
- Clay has a large surface area and it is electrically charged. The charge gives clay capacity to hold plant nutrient ions on its surface in forms available to plants. Sand has a small surface area (of its soil particles) and therefore lacks this capacity.
- Soils containing too much clay though have high water holding capacities but inadequate aeration. Sands have problem of too little water in them.
- When wet, clay soils stick to tools and implements and become hard when dry.
- Texture gives indication of the physical properties of the soil. Soil texture is referred to as light or heavy. Ploughing and other tillage operations require more power in clay soils than in sandy soils. Soils high in clay are therefore known as “heavy” soils and sandy soils are called “light” soils. However the actual weight of soil solids is greater in the sandy soil than in the clay soil.
- In consequence of varying influences of the texture on plant growth different crops are better suited to different textural classes of soils. For example paddy, jute and *dhaincha* (*Sesbania aculeata*) are preferred on clay loams and heavy soils, whereas wheat, gram and cotton on loams.

Changes in Soil Texture

Only mixing it with another soil of a different textural class can change texture of a given soil. For example, incorporation of large quantities of sand to improve the physical properties of a clay.

SOIL STRUCTURE

The arrangement of the primary soil particle, i.e. sand, silt and clay and their aggregates into a certain structural pattern are called soil structure. Naturally occurring aggregates in soil are called peds whereas clod is formed artificially by tillage.

Classification of Soil Structure

Soil structural units are described by three characteristics, i.e. type (shape), class (size) and grade (strength of cohesion)

Grade of Soil Structure

It refers to the distinctness, stability or strength of the peds as observed in the field. It is determined by noting the stability of peds. The grade may be:

Structure-less: No peds are observed in soil. Natural cleavage planes are

indistinct. This may be (i) Single grain: Sand behaves as single grain. Such soils have good infiltration rates and aeration. (ii) Massive: The soil mass clings together. Soils containing significant amounts of clay stuck together. Such soils lack permeability, e.g. dense soil crusts, fragipans.

Structured: In this structure natural cleavage planes are indistinct.

The structural grades are (i) Weak: Poorly formed indistinct peds. (ii) Moderate: Fairly well formed peds. They are durable. (iii) Strong: Well-formed distinct peds, which are durable. When such peds are broken then there is no unaggregated material.

Class of Soil Structure

It refers to the size of peds as shown in Table 9.2.

The term thin and thick are used for platy types, while the terms fine and coarse are used for other structural types.

Types of Soil Structure

Type refers to the shape of soil aggregates (Fig. 9.4). Shape of peds can be described according to the relative lengths of the horizontal and natural axis.

Spheroidal: This includes granular and crumbs subtypes. The peds (aggregates) are rounded, lie loosely and are separated from each other. This is considered the most desirable structure. This is a characteristic of A horizon rich in organic matter. This type of aggregation is influenced by soil management practices. Relatively non- porous aggregates are termed as granular. When the granules are porous, they are termed as crumb.

Platy: When the peds are in the form of thin plates. Horizontal axis of peds is much larger than their vertical axis. They are arranged in overlapping horizontal layers. This reduces the penetration of air water and roots. Soil compaction can create platy structure. Platy type is often inherited from parent material.

Prismatic: This includes columnar and prismatic sub types. Peds are large. They are characterized by vertically oriented aggregates. Prismatic structure often occurs in subsurface horizons in arid and sem-arid regions. When the tops of the prisms are rounded the term columnar is used. When the tops of the prisms are flat, the term prismatic is used.

Blocky: This includes angular blocky and sub angular blocky sub types. The peds are cube like, with their three dimensions approximately equal. When the

Table 9.2. Class of structures (Diameter in millimeter)

Class	Platy	Angular, sub angular prismatic or columnar	Spheroidal (granular crumb)
Very fine or very thin	less than 1	5–10	less than 1
Fine or thin	1–2	5–20	1–2
Medium	2–5	10–50	2–5
Coarse or thick	5–10	20–100	5–10 (only granular)
Very coarse or very thick	more than 10	50–100	more than 10 (only granular)

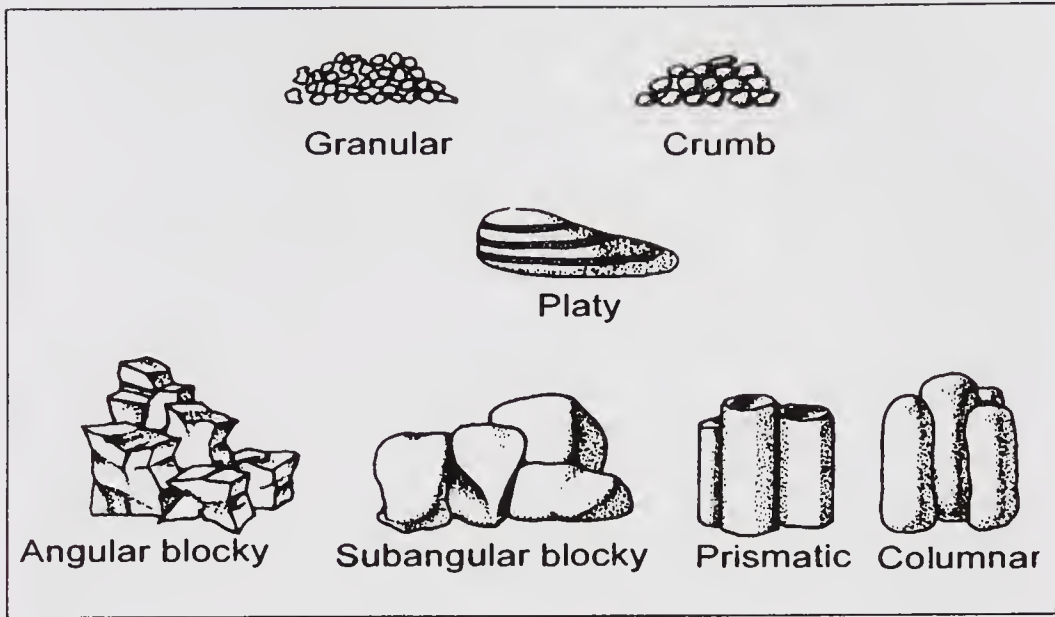


Fig 9.4. Type of soil structure

edges of peds are sharp angular, they are called angular blocky. When the faces and edges are removed, it is called sub angular blocky.

Naming Soil Structure

For naming a soil structure the following sequence is followed-grade, class and type. For example, a soil with fairly well formed peds (moderate) having diameter of 4 to 5 mm (medium) with rounded peds separated from each other present in the surface layers of a soil (granular) will be named as moderate medium granular.

Evaluation of Soil Structure

Soil structure can be evaluated by determining the extent of aggregation. Soil aggregates also reveal the distribution of pore-spaces. The susceptibility of aggregates to erosion is an important criterion in evaluating soil structure. Aggregate analysis may be done in two ways.

Wet and dry sieving: Dry sieving of soils is used to evaluate the distribution of clods and aggregates. It serves as an important index for characterizing the susceptibility of soils to wind erosion.

In wet sieving, the soil is allowed to moisten for $\frac{1}{2}$ an hour. Soil is transferred to nest of sieves immersed in water where they are in vertical motion (up and down motion of sieves in water). The weight of soil on different sieves is then determined.

Sedimentation method: This method is used to determine aggregate distribution in fractions that can not be separated by sieving. (For aggregate sizes less than 1mm).

Stability of aggregates can be evaluated by

- Stability against disruption during wet sieving.
- Stability against the falling drops of water.

- Stability against disintegration during leaching against dilute NaCl solutions.
- Stability against slaking when penetrated with alcohol or other organic solvents.

MECHANISM OF SOIL STRUCTURE FORMATION

It deals with conditions that holds together the individual textural units of a soil and builds them into aggregates. It includes causes and methods of formation of structural units or aggregates. The following mechanisms play important role in soil aggregate formation:

- Water molecules are dipolar, i.e. it posses both negative and positive charges. The negative end of a water molecule attracts the positive end of a second water molecule. The negative end of the second water molecule attracts the positive end of the third water molecule. In this way, long chains of water molecules are formed in nature. Cations are thus attracted to the negative ends of a chain of dipolar water molecules. Clay particles (being negatively charged) are attracted towards positive end of water molecule. Thus bridges of oriented water molecules and cations hold clay particles. When this chain of water molecules shortens, due to dehydration, the clay particles are united. (Fig 9.5)
- Organic compounds are formed during the decomposition of soil organic matter. Humic acid, polysaccharides are high molecular weight polymers. Humic acids and fulvic acid being negatively charged are attracted on the positively charged sites. Polysaccharides are strongly adsorbed on the surfaces of clay minerals. The adsorbed polymer replaces water on the surfaces of clay minerals. This helps in the binding of clay particles.
- Due to swelling and shrinkage in soil mass, cracks are formed in soil mass. This soil mass is bound by organic substances, iron oxides, clays, and carbonates. Thus soil aggregates are formed.
- Cementing agents like iron and aluminium oxides stabilize soil structure. The cementation effect of precipitated phosphates of iron and aluminium after their chemisorption on soil particles may cause aggregation. The mechanism is,

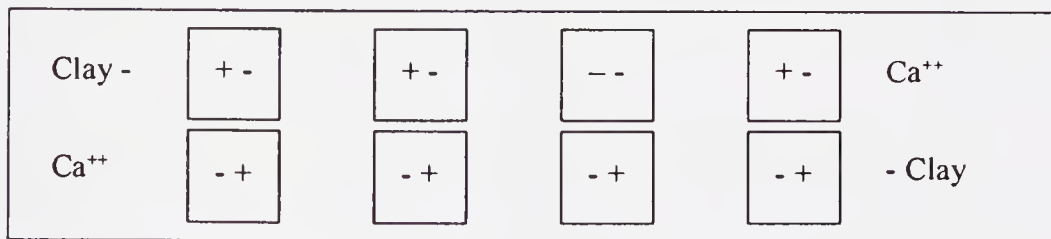
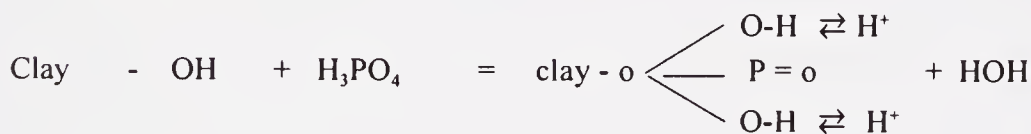


Fig 9.5. Two negatively charged clay particles joined together by a bridge of water molecule and calcium

- Soil micro-organisms produce microbial gums and synthesis polysaccharides. Both these products bind soil particles to form aggregates.
- Vegetation plays an important role in the genesis of soil structure. The beneficial effects of vegetation are because of following reasons:
 - It produces residues that are sources of energy for microbial activity.
 - Organic and inorganic secretions provide energy for microbial activity.
 - Roots produce substances that cement soil aggregates
 - Roots through their pressure cause compaction and are responsible for aggregation.
 - Vegetation offers a protection on the stability of surface aggregates against the destructive action of raindrops.

FACTORS AFFECTING FORMATION OF STABLE AGGREGATES

The stability of aggregates refers to the resistance of soil aggregates against the forces of its disruption. The primary soil particles should be firmly held together so that they do not disperse in water. Water and excessive tillage may disintegrate soil aggregates. Water causes deterioration of soil aggregates by:

- Its hydration, which results in swelling and exclusion of entrapped air.
- Falling rain drops which causes dispersion of aggregates. The dispersed soil particles may be carried into soil pores thus causing soil compaction. It may lead to the formation of crust. Effect of disruption of soil aggregates by tillage can be minimized if tillage practices are performed at optimum soil moisture contents.

The arrangement of soil particle into aggregates of desirable shape and size to provide an adequate amount of large pores is an important feature of soil structure. Another important feature is the stability of aggregates when exposed to water. Water stable aggregates maintain the ability of the soil to absorb water and help it to resist erosion. The stability of aggregates is related to soil texture, the kind of clay, the kind of ions associated with the clay, the kind and amount of organic matter present, and the nature of microbial population. Following factors influence stability of aggregates.

Organic Matter

It can be said that greater the percentage of readily decomposable constituents in the organic matter, the greater is the aggregating effect and quantity of water stable aggregates. The aggregates formed during alternate wetting and drying or freezing and thawing are stabilized by the presence of organic matter. Effect of organic matter in formation of stable aggregates can be enlisted as below:

- Being loose and porous, organic matter reduces the cohesion and plasticity of clay, and is responsible for the porosity of individual soil aggregates.
- Some of the decomposition products of organic matter and the associated microbial tissue act as cementing agents. Thus it has a stabilizing effect.
- Organic matter helps in the granulation of clay.

Plants

Effects of vegetation in formation of stable aggregates can be summarized as:

- Plant foliage protects soil aggregates against the disintegrating action of raindrops.
- Root hairs penetrate clods, thus breaking the soil clods into desirable aggregates.
- Root excretions, water sorption by roots and pressure exerted by root penetration are conducive to formation of stable aggregates.
- Grasses and legumes can restore deteriorated soil structure.

Soil Organisms

- Decomposition of organic matter by micro-organisms produces humic acids, polysaccharides that impart stability to aggregates. Thus soil micro-organisms are indirectly helpful in formation of stable aggregates.
- Macro-organisms like rodents and earthworms help soil aggregation by burrowing, turning and mixing the soil. Earthworm's activity has a remarkable effect in the formation of stable aggregates. They excrete surface casts and form burrows, which promotes granulation.
- The mechanical binding action of cells and filaments of the organisms helps in stability of soil aggregates.

Adsorbed Cations

- Adsorption of ions such as Ca^{2+} , Mg^{2+} , Al^{3+} or H^+ encourages flocculation, which is the primary step towards formation of aggregates.
- Ca^{++} and Mg^{++} are also indirectly effective in promoting granulation due to their favorable influence on microbial activity.
- Na^+ being a highly hydrated cation is not tightly held by the micelle thus do not encourage aggregation. It causes dispersion.
- Floccules may achieve stable granulation through cementation by clay, humus, other colloidal materials and oxides of iron and aluminium.

Climate

- The percentage of stable aggregates is higher in soils of semi-arid and semi-humid regions. This is because these contain higher amounts of divalent bases like Ca^{++} and Mg^{++} .
- In soils of desert and humid regions there is either very little clay formation or clay formed is eluviated to lower horizons. This is because under these two extremes of desert and humid regions weathering processes are slow, thus adversely affecting formation of clay and stable aggregates.
- Organic matter content is lowered with rising temperature in arid regions. This adversely affects formation of aggregates.

Tillage

- Tillage promotes aggregation by making the conditions more favorable for the activity of natural forces of granulation.
- Excess tillage tends to destroy aggregate structure.

Soil Conditioners

- Naturally occurring organic polymers, polysaccharides, and polyuronides are major synthetic polyelectrolytes contributing to soil aggregation. They

stabilize soil aggregates through a mechanism similar to the naturally occurring polymers. Clays through cation exchange adsorb polycations. Calcium ions act as bridges between the clay and organic polymer. Thus these polymers stabilize soil aggregates at very low concentrations.

From the above discussions, it can be summarized that aggregate stability is affected by:

- Mechanical binding action of micro-organisms especially the thread like filaments of fungi.
- The cementing action of products of microbial synthesis, such as gums and polysaccharides.
- The cementing action of humus components and inorganic compounds, such as iron oxide.

ADHESION AND COHESION

Adhesion and cohesion are two important forces, which hold water in the soil. Adhesion, is the attraction of soil water to soil particles; while cohesion, is the attraction of water molecules to another water molecules.

ADHESION AND COHESION PHENOMENON

Water molecule plays a significant role in both these phenomenon. Hydrogen consists of one proton and one electron. Two hydrogen atoms combine with oxygen to form water, each (hydrogen atom) shares its one electron with the oxygen atom. Thus each electron lies between the oxygen and hydrogen atoms, leaving the positively charged protons on one side of the molecule. As a result the side with protons has a positive charge. To balance this positive charge, the oxygen side assumes a negative charge. The water molecule is positive on one end and negative on the other end. The opposite ends of water molecules attract like magnets. The bond between the hydrogen of one water molecule and the oxygen of another is called a hydrogen bond. Hydrogen bond accounts for cohesion (Fig. 9.6).

Hydrogen bonding is the attraction of the positively charged hydrogens of water to both its oxygen and to nearby negatively charged ions (say another oxygen). Hydrogen's of water bond strongly to these surface oxygen atoms. This is called adhesive bonding. The hydrogens of water are also attracted to oxygens of other water molecules. This is called cohesive bonding. Two water molecules attract each other because the plus side attracts the minus side, forming a hydrogen bond.

Hydrogen bonding also accounts for adhesion. This may be explained on the basis that quartz, one of the main soil forming mineral with chemical composition, SiO_2 has oxygen atoms on its surface. It can form hydrogen bonds with soil water.

The phenomena of adhesion and cohesion could be explained together under natural soil conditions as follows:

Some water molecules are held rigidly at the soil solid surfaces. In turn, these tightly bound water molecules are held by cohesion with other water molecules. This is presented in Fig 9.7.

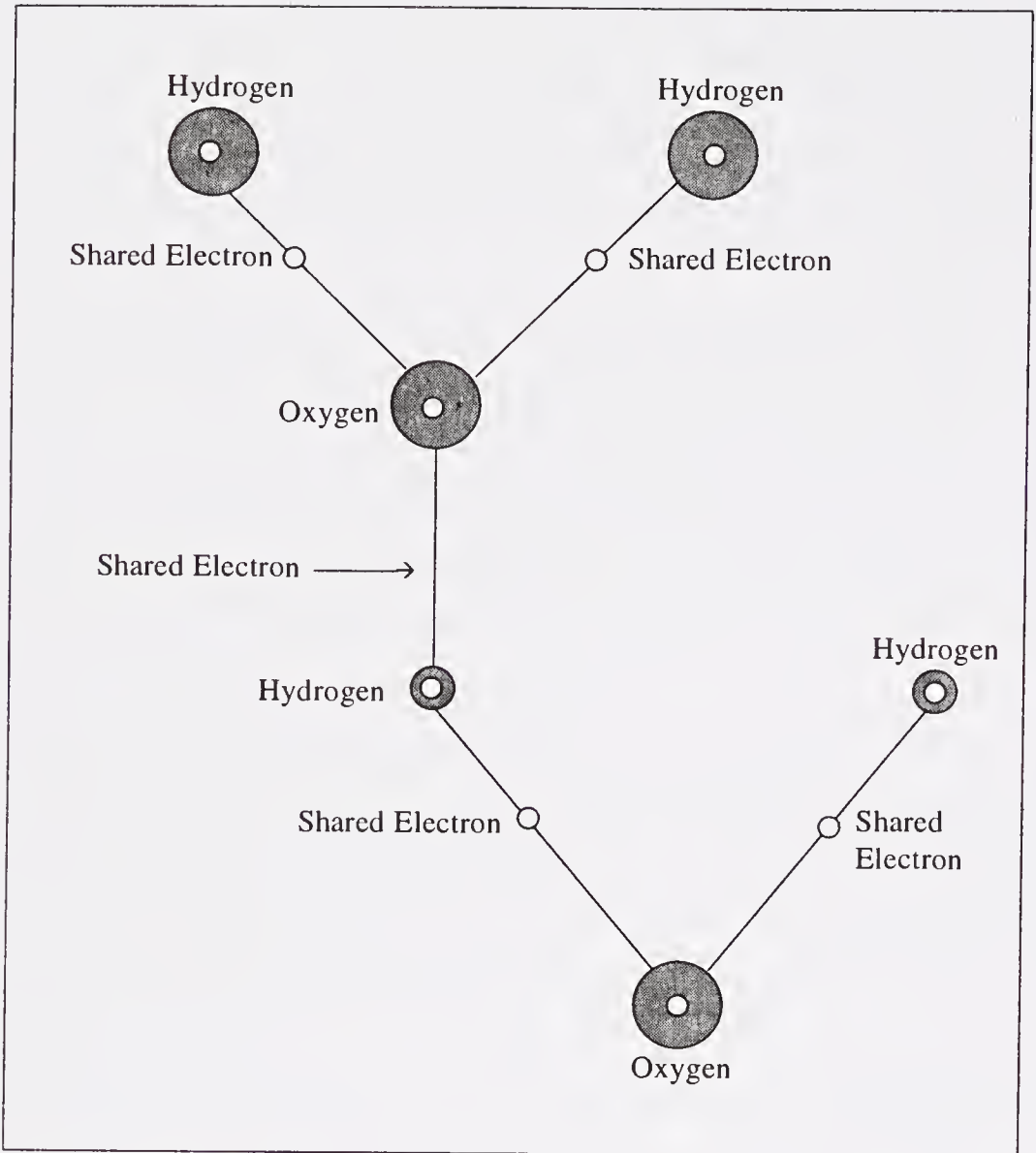


Fig. 9.6. A Hydrogen Bond

FLOCCULATION AND DEFLOCCULATION

When individual tiny soil particles, especially fine clay, aggregate together into small clumps or floccules, the phenomenon is called flocculation. It is beneficial since it adds in the formation of stable aggregates. Cations flocculates soil colloids in the order $\text{Al}^{3+} > \text{H}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$.

The opposite of flocculation, which separates the individual components of compound particles by chemical or physical means, is called deflocculation or dispersion. Deflocculation is caused because of the following reasons:

Negative charges on clays: Repulsion of negatively charged particles for each other as in clays.

Sodium ion: Na^+ ion is not held tightly by the micelles. Hence, more tightly held cations such as Ca^{++} , Mg^{++} inhibit adsorption of Na^+ , Na^+ ions do not reduce

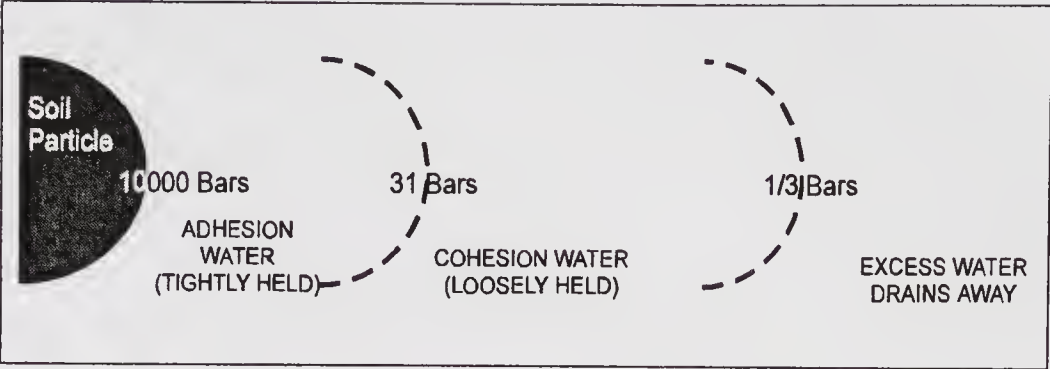


Fig. 9.7 A water film, showing bars of potential

electronegativity of the micelle also (being loosely held). Thus the micelle continue to repel each other.

Hydration of ions: Sodium and lithium ions become highly hydrated thus increasing the thickness of diffuse double layer, due to their bigger size (given below). Thus the negative charge developed on clay particles keeps them in suspension.

Size of the Ion(A⁰)

Ions	Hydrated	Unhydrated
Lithium	10.03	0.78
Sodium	07.9	0.98

Deflocculation can be reduced by:

Flocculating ions: Replacing sodium by Ca²⁺, Mg²⁺, Al³⁺ and H⁺. These ions being flocculating agents reduce dispersion.

Lowering the soil pH: This will reduce electro-negativity, and thus dispersion. Higher the electronegativity, more the particles repel each other and remain in dispersion.

Addition of simple salts: Salts increase concentration of cations around the micelle and reduce electronegativity.

Practical Significance of Flocculation

Stable aggregates can be formed in soils containing clay that will flocculate. If clays remain dispersed, the soil puddles. Puddled soils are difficult to work. These soils are sticky when wet and hard when dry. As the soil becomes dry, soil compaction may occur which inhibit soil aeration. This adversely affects root growth. Thus, soil should contain clays that can flocculate. Ca and Mg having high flocculating powers can reduce toxic effect of high Na concentration.

BULK DENSITY AND PARTICLE DENSITY OF SOILS

Bulk density: It is defined as the mass per unit volume of total soil including

both soil solids and pores expressed on oven dry basis. This is expressed as megagrams per cubic meter (Mg/m^3). Bulk density of soil divided by density of water is known as apparent specific gravity. The bulk density of a soil is always smaller than its particle density. The bulk density of sandy soil and clayey soil if less than 1.4Mg/m^3 and 1.2Mg/m^3 respectively may be considered optimum for crop growth (Fig 9.8).

FACTORS AFFECTING BULK DENSITY

Texture: As a general rule, the finer textured soils have more pore space and lower bulk densities than sandy soils.

Soil depth: Bulk density is generally higher in lower layers. This is because of low organic matter and compaction caused by weight of the overlying layers. Packing a soil decreases its pore space and increases its weight per unit volume.

Organic matter: Organic matter is much lighter than the corresponding volume of mineral matter. Thus organic matter decreases bulk density. Organic matter gives increased stability to a soil.

Cultivation: It has varied effects :

- Cultivation reduces organic matter and thus increases bulk density.
- Bulk density of soils decreases if grasses are grown, because grass roots bind the soil particles to form soil aggregates. Grasses also add organic matter.

Practical Use of Bulk Density

- High bulk density values causes restricted root development.
- The average weight of furrow slice for a hectare is calculated by multiplying the soil volume by its bulk density.

One-hectare furrow slice of soil is the volume of the soil one-hectare in area

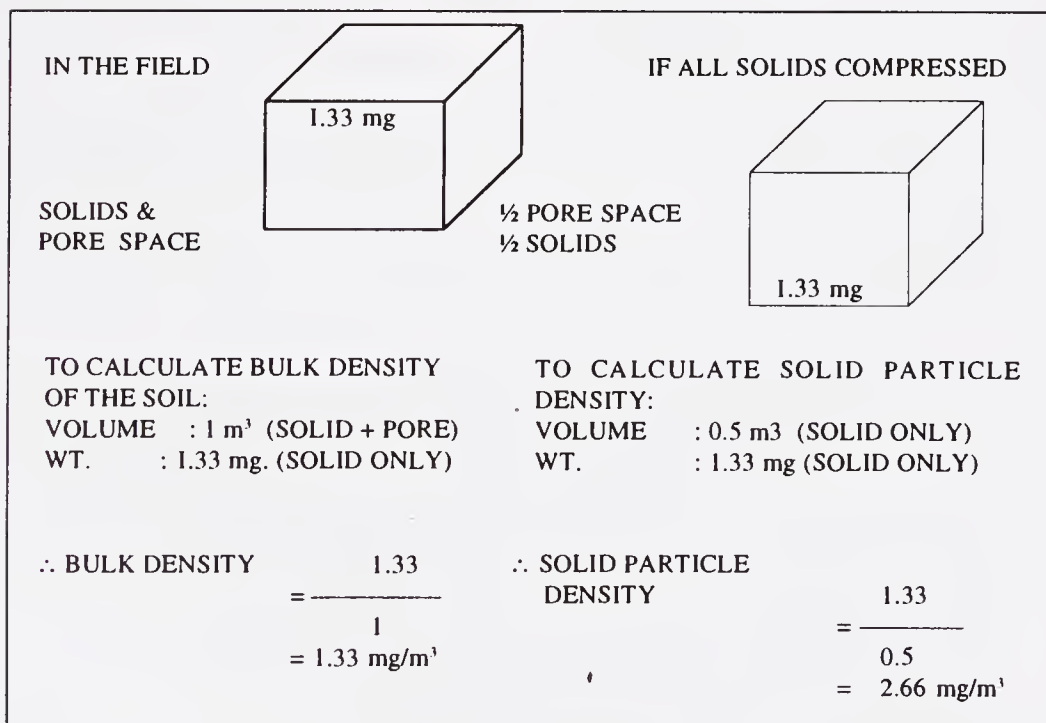


Fig 9.8. Bulk density and solid particle density

and 15cms in depth.

Volume of one hectare = $10000 \times 15/100$

$$(15 \text{ cms depth}) = 1500 \text{ m}^3$$

If the bulk density of surface soil is 1.3 Mg/m^3 or $1.3 \times 1000 = 1300 \text{ kg/m}^3$

Therefore, weight of one hectare of soil = 1500×1300

$$= 1950,000 \text{ kg.}$$

A hectare of furrow slice is therefore assumed to weigh 2 million kg.

2 million kg/ hectare is widely used for converting lab data for field use, if soil analysis is reported in ppm. Multiplication by 2 converts ppm to pp2m for use on kg/ha basis.

The use of ppm data can be illustrated by a soil containing, for example, 5ppm of available phosphorus. This is equivalent to 10kg/ha of available phosphorus (pp2 m = ppm $\times$ 2 i.e. $5 \times 2 = 10 \text{ kg/ha}$)

PARTICLE DENSITY

Particle density is the average density of soil particles i.e. excluding pore space. This is expressed as Megagrams per cubic meter (Mg/m^3).

Particle density depends on:

- The type of minerals in the parent material.
- The amount of organic matter in the soil. Organic matter reduces the value because it is much lighter than mineral matter.

Particle density of soil can be determined by adding densities of the soil constituents. The dominant soil forming minerals are quartz, feldspars, micas and clay minerals. The densities of these minerals range between $2.60\text{--}2.75 \text{ Mg/m}^3$. Hence in most soils average value of particle density is about 2.65 Mg/m^3 . If minerals like zircon, magnetite and tourmaline, possessing higher densities (more than 2.75) are present, the particle density may exceed.

SOIL POROSITY

The pore space of a soil is portion of the soil volume occupied by air and water. This when expressed as per cent is known as porosity. Thus, a soil with 50% porosity is half solid particles and half pore space. The per cent pore space is calculated from data on bulk density and particle density. Given these two values, the per cent of the soil volume occupied by solids is

$$\text{Per cent Solid} = \frac{\text{bulk density}}{\text{particle density}} \times \frac{100}{1}$$

Per cent pore space = $100 - \text{per cent solid}$

$$\text{Per cent pore space} = 100 - \frac{\text{bulk density}}{\text{particle density}} \times \frac{100}{1}$$

$$\text{Or usually per cent pore space} = \left(1 - \frac{\text{bulk density}}{\text{particle density}}\right) \times 100$$

Thus, increasing bulk density means an increased percent solid and a decrease

in per cent pore space. Root growth and water penetration are adversely affected with bulk density exceeding 1.50 Mg/M^3 .

Porosity of soil indicates total pore space and not the size and form of individual pores. Macro-pores (non-capillary pores) allow a ready movement of air and water but do not hold much water. Micro-pores (capillary pores) can hold more water but the movement of air and water is restricted. Size of individual pores rather than total pores space in a soil is more significant for plant growth relationship. A soil should have about an equal amount of macro and micro-pores to provide favorable moisture and air relations for most plants.

Sandy surface soils have total amount of pore spaces ranging from 35 to 50%, heavy soils from 40 to 6%. Soils from lower depths are compact with 20 to 30% pore spaces. Cropping reduces the size of macro pores and proportionally increases the size of micro-pores.

SOIL CONSISTENCE (Plasticity, Stickiness)

The cohesiveness holding soil particles together in clumps is called soil consistence. It refers to the behavior of soil when pressure is applied. Soil consistence is due to the forces of adhesion and cohesion. Clays, due to their large surface area have more cohesive forces. The force of molecular attraction is greatest in dry soil and decreases as water enters between soil particles. Clays also exhibit a thixotropic character (due to small size of clay particles they are oriented close to each other, thus molecular attraction is more effective). When the soil is fully saturated, the adhesive and cohesive forces are zero.

Factors Affecting Soil Consistence

Soil consistence is affected by the :

Type of clay: Consistence is more in montmorillonite (2:1 type clays) due to large surface area.

Texture: Soil consistence increases with increasing fineness

Structure: Soil consistence is more in a puddled soil than a well aggregated soil because of greater areas of contact between the individual particles.

Presence of iron and aluminium oxides and hydroxides: Consistence increases with increase in their contents due to an increase in cohesiveness holding soil particles together. A complete description of soil consistence requires that the soil be tested in the dry, moist and wet conditions, so that soil consistence can be evaluated on all these scales (Table 9.3).

Consistence when dry: A dry soil may be loose to very hard as indicated in Table 9.3. These terms indicate the resistance offered by soil to root penetration and the power required to cultivate the soil. In general, increasing the clay content of a soil will make it harder because clay particles stick to each other.

Consistence when moist: It is determined when soil is slightly wet i.e. in between the air dry and field capacity moisture content. It is described as loose to extremely firm. Soil materials can be crushed easily under pressure. Firm soils require distinct pressure to break.

Consistence when wet: It is determined when the soil is nearly saturated with water. Wet soil is checked for stickiness and plasticity.

Table 9.3. Consistence terms for soil at different moisture levels.

Dry	Moist	Stickiness	Plasticity
Loose	Loose	Non sticky	Non plastic
Soft	Very friable	Slightly sticky	Slightly plastic
Hard	Firm Friable	Sticky	Plastic
	Very firm		Very plastic
Very hard	Extremely firm	Very sticky	

Stickiness and Plasticity

Stickiness: It is a measure of the tendency of a wet soil to adhere to other objects. Sandy soils are not sticky. Increasing clay content makes soils slightly sticky to very sticky. Stickiness disappears when the water content drops below field capacity or rises above saturation.

Plasticity: It is the ability of soil mass to take or hold a new shape when pressure is applied or removed. A non-plastic soil mass will fall apart when pressure is removed. Increasing plasticity is correlated with increasing clay content. Soils with less than 15% clay do not exhibit plasticity in any moisture range.

A specific plastic number characterizes different soils, which is the difference between moisture contents of a soil at its upper and lower plastic limits. Upper plastic limit, represents the moisture content of a soil at a given point where the soil water mass just flows under an applied force and fails to retain its shape. Lower plastic limit, refers to the moisture content of a soil at a point where its consistence changes from plastic to friable and the soil water mass is unable to change shape continuously under the influence of an applied force, and ultimately the mass breaks into fragments.

References and Suggested Readings

Means, R.E. and Parcher, J.V. (1965). *Physical Properties of Soils*. Prentice Hall of India Pvt. Ltd., New Delhi.

Oswal, M.C. (1983). *A Textbook of Soil Physics*. Vikas Publishing House Pvt. Ltd., New Delhi.

Thompson, L.M. and Troeh, F.R. (1985). *Soils and Soil Fertility*. Tata McGraw Hill Publishing Co. Ltd., New Delhi.

QUESTIONS

Q. 1. Fill in the blanks

- i) Reddish colours of soils are characteristics of well _____ conditions. Under reducing conditions bluish gray colour occurs.
- ii) _____, indicates the purity of the dominant colour.
- iii) The well developed red colour of soils is due to intense _____.
- iv) The notation for value consists of numbers from 0, for absolute black, to 10 for absolute _____.
- v) Mechanical analysis is also known as _____.
- vi) The texture of soil is an almost _____ character.

- vii) Sand is chemically _____.
- viii) Silt has the ability to hold a large amount of _____ in a form that plants can use.
- ix) When wet, _____ soils stick to tools and implements and become hard when dry.
- x) The soil textural triangle is divided into _____ compartments.
- xi) Soil textural units are described by three characteristics _____, _____ and _____.
- xii) _____ of soil structure refers to the distinctness, stability or strength of peds as observed in the field.
- xiii) The structural grades are _____ strong.
- xiv) _____ refers to the size of peds.
- xv) Prismatic structure includes two sub types i.e. columnar and _____.
- xvi) When the faces and edges in blocky structure are rounded the structure is called _____.
- xvii) For naming a soil structure, the following sequence is followed _____ and _____.
- xviii) The stability of aggregates refers to the _____ of soil aggregates against the forces of its disruption.
- xix) Polyelectrolytes (polycations) are adsorbed by clays through _____.
- xx) The susceptibility of aggregates to _____ is an important criteria in evaluating soil structure.
- xxi) Finer fractions (aggregates < 1mm) that can not be separated by sieving during aggregate analysis, are determined by _____.
- xxii) Bulk density of soil is expressed as _____.
- xxiii) Bulk density of soil _____ if grasses are grown, because roots bind soil particles and also add organic matter.
- xxiv) The average weight of soil for a hectare is calculated by multiplying the soil volume by its _____.
- xxv) If a soil contains 10 ppm of available phosphorus, this equivalent to _____ kg/ha.
- xxvi) Presence of organic matter _____ particle density.
- xxvii) The densities of important soil forming minerals ranges between _____ to _____ mg/m³.

Answers

- i) oxidized ii) Chroma iii) weathering iv) white v) particle size analysis vi) Permanent vii) inactive, viii) Water, ix) clay, x) twelve xi) type class and grade
- xii) Grade, xiii) Weak, moderate, xiv) Class, xv) prismatic, xvi) sub angular blocky xvii) Grade, class, type, xviii) resistance, xix) cation exchange xx) erosion xxi) sedimentation methods xxii) Mg/m³ xxiii) decreases xxiv) bulk density xxv) 20 xxvi) decreases xxvii) 2.60 – 2.75.

Q. 2. Choose the correct answer

- i) With increasing stage of soil development following increased temperature

- and rain fall, the soil colour tend to become brownish or reddish / grayish.
- ii) Hue / chroma is related to dominant wavelength of light.
 - iii) Silt / clay feels smooth like flour or talcum powder when dry.
 - iv) The weight of soil solids is greater in the sandy / clay soil.
 - v) Type / class refers to the shape of soil aggregates.
 - vi) $\text{Na}^+/\text{Ca}^{++}$ being highly hydrated cation is not tightly held by the micelle.
 - vii) The bulk density of a soil is always smaller / greater than its particle density.
 - viii) Organic matter is much lighter / heavier than the corresponding volume of mineral matter.

Answers

- (i) brownish or reddish (ii) Hue (iii) Silt (iv) sandy (v) Type (vi) Na^+ (vii) smaller (viii) lighter

Q. 3. Define the following

- (i) Mottles (ii) Soil texture (iii) Specific surface (iv) Chemisorption (v) Soil separates (vi) Mechanical analysis (vii) Soil structure (viii) Hydraulic conductivity

Q. 4. Differentiate between

- (i) Lithochromic colour and genetic colour (ii). Importance of soil texture with reference to clay and sand (iii) Ped and Clod (iv) Grade and type of soil structure (v) Angular blocky and Subangular blocky type of soil structure (vi) Aggregate analysis by Wet and Dry sieving (vii) Adhesion and Cohesion (viii) Flocculation and De-flocculation.

Q. 5. Write short notes on

- (i) Loam soil (ii) Surface area effect (iii) International pipette method (iv) Role of organic matter in the stabilization of soil aggregates (v) Evaluation of aggregate stability (vi) Soil consistence when wet.

Q. 6. Comment on the following statements

- i) Darker coloured soils are richer in clay and more fertile than lighter coloured soil
- ii) Sometimes darker soils may not warm up quickly.
- iii) Loam soils are highly desirable for most uses.
- iv) Particles larger than 2 mm are excluded from soil texture determinations.
- v) Soils high in clay are known as “heavy” soils and sand soils are called “light” soils.
- vi) Vegetation plays an important role in the genesis of soil structure.
- vii) Tillage may promote or destroy aggregation.
- viii) Percentage of stable aggregates is higher in soils of semi arid and semi humid regions as compared to soils of humid climate.
- ix) In desert and humid regions clay content adversely affects formation of stable aggregates.
- x) Water causes disintegration of soil aggregates.
- xi) Soil organisms are helpful in formation of stable aggregates.
- xii) Bulk density is generally higher in lower soil profiles.

- xiii) Under warm humid regions, soils are red.
- xiv) A hectare of furrow slice is assumed to weigh 2 million kg / hectare.
- xv) In most soils the average value of particle density is about 2.65 mg / m³.
- xvi) Size of individual pores rather than the % pore space in a soil is more significant in its plant growth relationship.

Q. 7. Answer the following in brief

- i) What is the importance of physical properties of soil. Explain them.
- ii) What is the significance of soil colour?
- iii) How are Munsell colour notations written?
- iv) What is the importance of soil texture?
- v) What is the method of finding the approximate number of particles per gram of soil?
- vi) How will you judge sand, silt and clay by feel method?
- vii) Can soil texture be changed? If yes, How?
- viii) How is soil textural triangle prepared?
- ix) Explain the mechanism of clay particles being held together by bridges of oriented water molecules and cations.
- x) What is meant by stability of soil aggregates.
- xi) Floccules may achieve stable granulation through cementation. Enlist such cementing agents.
- xii) What is the practical significance of plasticity
- xiii) How does soil texture and organic matter affect bulk density.
- xiv) Express the relationship between bulk density, particle density and per cent pore space.
- xv) What are the causes of deflocclation? How it can be reduced.
- xvi) Enlist factors that may impart black colour to soils.

Q. 8. Answer the following in detail

- i) Explain Stoke's law with its formula. What are the assumptions of this law.
- ii) Explain the mechanism of soil structure formation.

Q. 9. Give diagrammatic view of the following

- i) The phenomena of adhesion and cohesion.



10

Soil Water

Water influences all soil phenomena and plant life.

- Water is essential for weathering, formation of parent material, development of soil profile and physical characteristics of soil.
- Nearly 90% of plant tissues consist of water. In respect of plant life, water serves as a solvent and a carrier of plant nutrients. Water keeps plant cell turgid and regulates their temperature through transpiration from the leaves of plants.
- Water is essential for the growth of micro-organisms, decomposition of organic matter and all chemical and biological activities.

The soil water containing nutrient ions is known as the soil solution. A moderately textured soil contains about 25–30% water of its volume and only half of this is available to plants. This is most favorable from the point of view of availability of water. Sandy soils hold low amounts of water available to plant, following their wetting and thus need frequent supply of water to support plant life. Clay soils on the contrary have the problem of poor drainage. The soil is important as a reservoir to meet plants requirement of water. This is greatly modified by physical properties of soil like texture, structure, compaction, clay and humus colloids.

STRUCTURE OF WATER

Water is a covalent molecule having formula H_2O . In the formation of water molecules, two electrons are mutually shared with two hydrogen atoms to form two O-H covalent bonds as shown in Fig. 10.1. Thus, there are two bond pairs

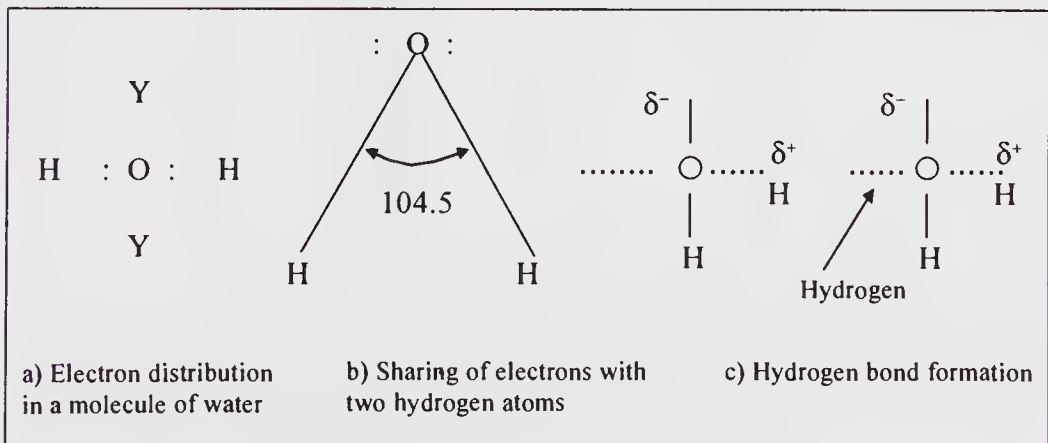


Fig. 10.1. Structure of a water molecule

and two lone pairs around oxygen atom. The presence of two lone pairs makes the water molecules bend at one angle of 104.5° .

Since oxygen is more electronegative than hydrogen, the shared bond pairs lie closer to oxygen atom. As a result oxygen atom acquires partial negative charge (δ^-) whereas hydrogen atom acquires partial positive charge (δ^+). Because of polar O-H bonds and bent structure, water molecules are highly polar.

Since oxygen atom carries a partial negative charge and hydrogen atoms carry partial positive charge, therefore, oxygen atom of a water molecule can have attractive interaction with hydrogen atom of the other molecule. This type of force of attraction between hydrogen atom of one molecule and electronegative atom of the other molecule is called hydrogen bond. It is because of these intermolecular forces that water has high boiling and freezing point, high heat of fusion and vaporization and high density.

WATER PRESSURE IN A CAPILLARY TUBE

If a capillary tube is inserted in a beaker of water, the attraction between glass and water molecules (adhesion) causes water molecules to migrate up the interior wall of the capillary. The cohesive force between water molecules causes other water molecules to be drawn up the capillary. Water pressure decreases from the bottom to the top of the beaker and at the top of the water surface the water pressure is zero. Thus the water pressure in a capillary tube is less than zero or is negative. From Fig. 10.2 one can observe that water pressure decreases in a capillary tube with height above the water in a beaker.

The height of rise in a capillary tube is inversely proportional to the diameter

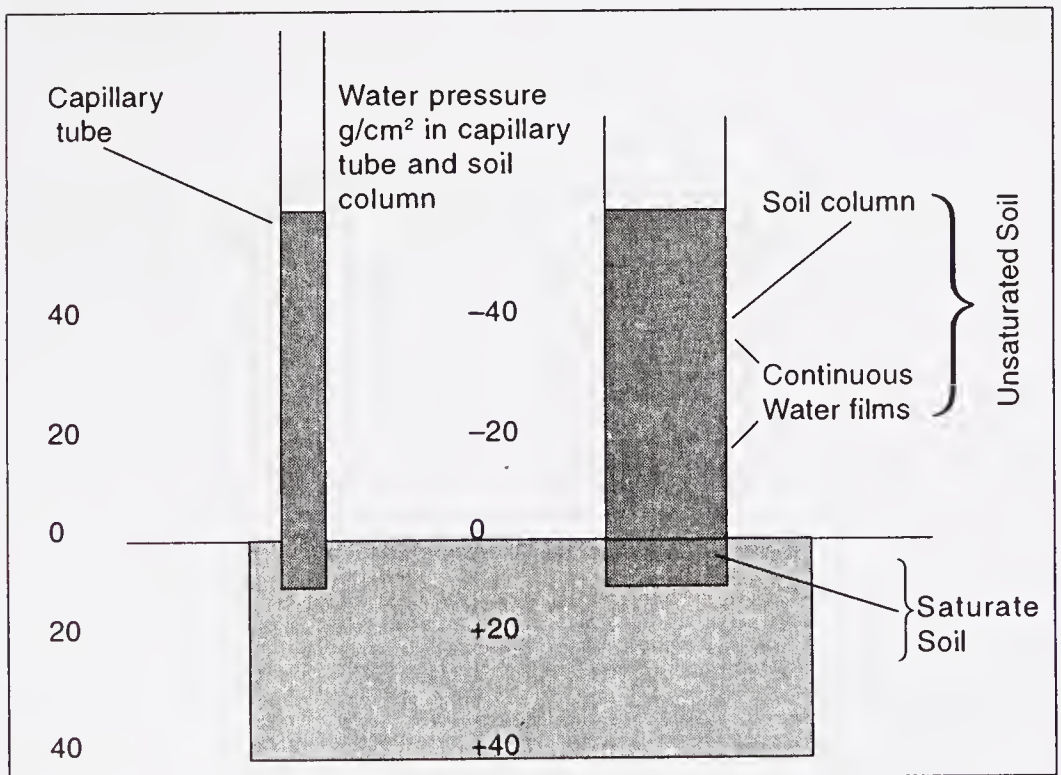


Fig. 10.2. Water pressure in a capillary tube

(2r) of the tube and directly proportional to the surface tension. The capillary rise is

$$h = \frac{2r}{Rdg}$$

Where h is the height of capillary rise in the tube, T is the surface tension, r is the radius of the tube, d is the density of the liquid, and g is the force of gravity. For water, this equation is

$$h = \frac{0.15}{r}$$

This equation emphasizes the inverse relation between height of rise and size of the tube through which water rises.

Surface tension may be defined as the force in dynes acting at right angles to any line of 1 cm. length in the surface. Surface tension influences the phenomenon of capillarity as follows: At the surface, the attraction of air for water molecules is much less than that of water molecules for each other. This results in the net downward force on the surface molecules resulting in a sort of compressed film at the surface. This results in capillary rise. Soil water is held by adsorption and capillary forces. The pores are the spaces between soil particles. The soil capillaries are not straight uniform tubes.

Capillary forces are at work in most soils. The upward movement due to capillary in soils is illustrated in Fig 10.3. Usually the height of rise resulting from capillary force is greater in fine textured soils. This could be attributed to small size of pores and their continuity in such soils. In coarse textured soils the

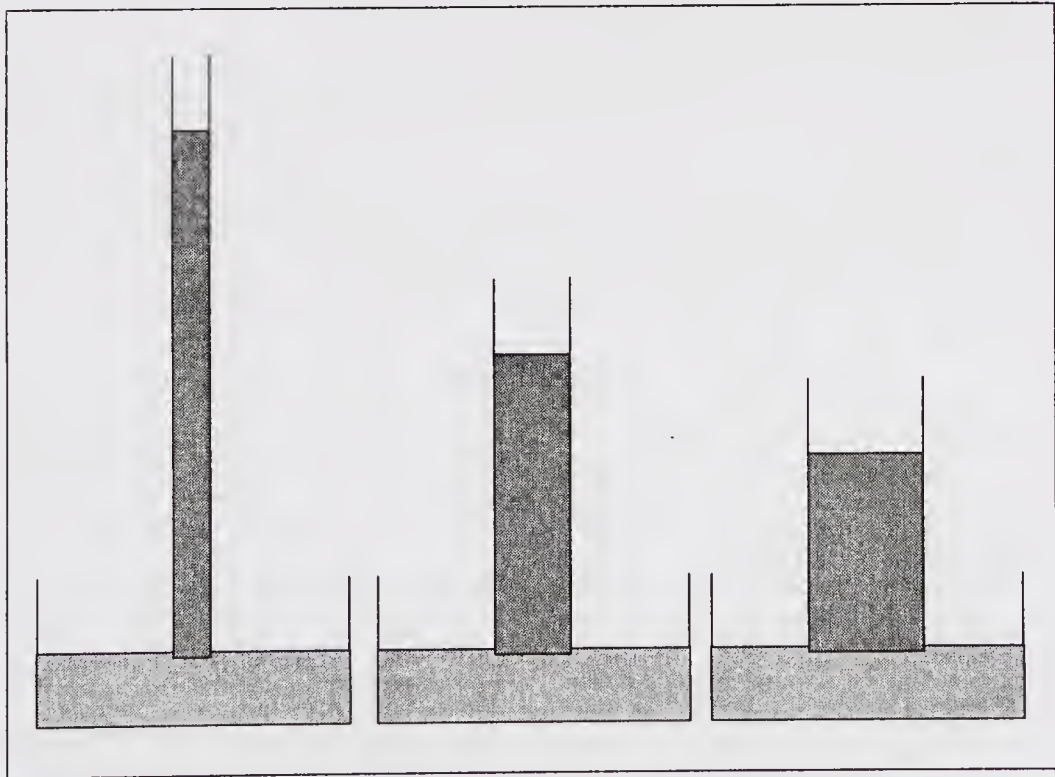


Fig. 10.3. Upward movement by capillarity in glass tubes of different sizes

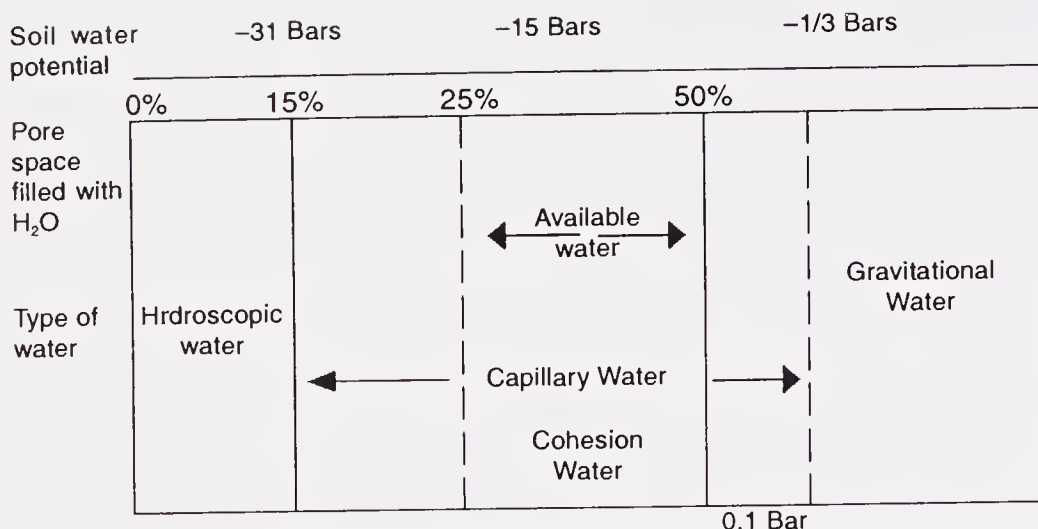


Fig. 10 4. Types of soil water, water potential in bars and pore spaces at each constant pores are non-capillary. Capillary forces involve the attraction between soil pores and water, horizontally as well as vertically.

CLASSIFICATION OF SOIL WATER

Physical Classification

Gravitational water: Water that moves under the influence of gravity. Such water is present in the macro pores. It is held by soil with a force of less than 0.1 bar. Water in excess of field capacity is gravitational water and is thus called superfluous. Such water if present over long periods in the soil interferes with aeration and is detrimental to plants.

Capillary water: Water held by surface tension in soil capillaries after the gravitational water has been allowed to drain away. It is held in micro pores at tensions between 0.1 – 31 bars. Capillary water is the main source of available water to plants.

Hygrosopic water: This water is very tightly held to soil particles, therefore plants cannot absorb it. Water is held with a force between 31–10,000 bars. This mostly is non liquid or in vapor form (Fig 10.4).

Biological Classification

The biological classification of soil moisture is based on its availability to plants. There is a definite relationship between moisture retention and its use by plants.

Available water: Available water is the moisture retained, between the field capacity and the wilting coefficient i.e. between 1/3 atmosphere (–0.3 bar) to 15 atmospheres (–15 bars)

Unavailable water: Water that is held at more than 15 atmospheres (–15 bars) is called unavailable water.

MOISTURE RETENTION IN SOIL: ENERGY CONCEPT OF SOIL WATER

Water is retained in soil due to forces of adhesion, cohesion, capillary forces and surface tension. These forces hold soil water against the force of gravity.

Several layers of water molecules are strongly adsorbed to the soil particles

because of strong adhesive forces. This water is called adhesion water. Adhesion water is not available to plants. Water molecules are held in the water film by cohesion. This outer film of water is called cohesion water. Molecules of cohesion water are in great motion, have a higher energy level and move readily. The water film in soils may be 15 to 20 molecular layers thick. Approximately 60% of this film is available to plants and constitutes the major source of water for plant growth. (For adhesion cohesion phenomena refer chapter 9).

The retention and movement of water in soils, its uptake and translocation in plants and its loss to the atmosphere are all energy-related phenomena.

Free energy (also called potential energy) characterizes the energy status of water. When work is done on soil water, for example it is raised to some higher elevation, then its free energy is increased. But when the clay particle or exchangeable cations absorb soil water itself, then its energy is decreased. Water moves from a state of higher free energy to a state of lower free energy.

Free energy is controlled by (i) Gravity, free energy of water located at a higher elevation is higher than the same water located at a lower elevation. (ii) The free energy of water held by cations and clay is less than the pure free water located at the same elevation as the soil water. It is thus clear that difference in energy levels from one point to another control movement of soil water. The different energy levels are explained here.

SOIL WATER POTENTIAL (Ψ)

The difference between the free energy of soil water and that of pure water at a reference state is called soil water potential. Free energy of pure water at reference point is considered zero. If the free energy of water at a particular point is more than the pure water at the reference point, it is considered positive. If it is less, it is considered negative. Soil water potential comprises of

- Gravitational potential (Ψ_g)
- Matric potential (Ψ_m)
- Osmotic potential (Ψ_o)

Gravitational potential (Ψ_g): It is positive, because work has been done on the soil water to raise it from the lower edge of the soil profile to the surface. From the surface water flows down under the influence of gravity.

Matric potential (Ψ_m): Matric potential is the result of adhesion and capillarity. It is due to the attraction of water by clay and humus. It decreases free energy of soil water. Hence matric potential is always negative.

Osmotic potential (Ψ_o): It is due to the attraction of water by exchangeable cations and soluble salts. It decreases free energy of soil water. Hence osmotic potential is always negative. Since matric potential and osmotic potential decrease free energy of water with respect to potential of pure water at the reference point and they are negative potentials, they contribute to soil moisture tensions. (Fig 10.5).

Mechanism of Water Retention by Soil

Based on the energy concept of soil water, the phenomena of retention of water can be better understood :

- When a dry soil absorbs water, water in this process loose free energy called heat of wetting. Thus, first layer of water molecules adsorbed on the clay

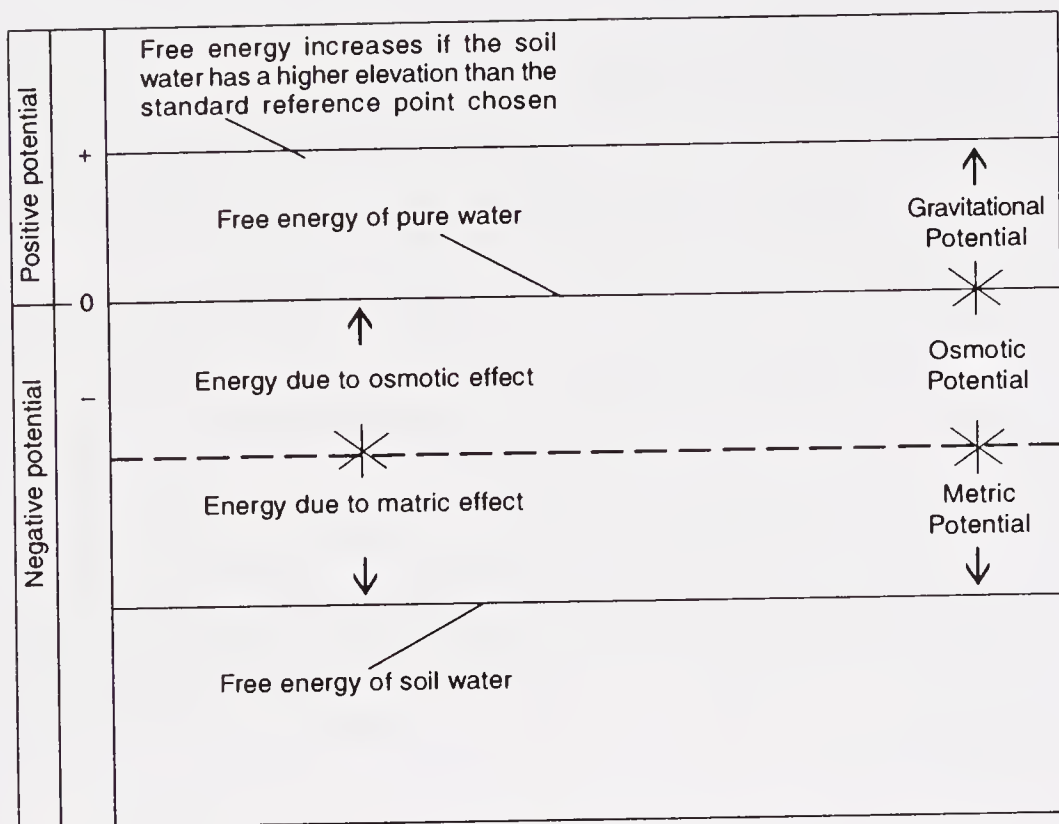


Fig. 10.5. Relationship between the free energies of pure water and of soil water

loses the maximum amount of free energy and therefore possesses the highest negative potential.

- The second layer of water molecules adsorbed over the first layer and subsequently the third layer of water molecules adsorbed over the second layer of water molecules loses a little less free energy as compared to the first layer.
- In this way; the negative potential of the succeeding layer of water molecules gradually decreases as the distance from the clay surface increases that is, the thickness of the moisture film around the clay increases till it becomes zero and then acquires a low positive value. This stage is reached when macropores are full of water (after flooding or heavy rains).
- At this stage, gravitational force works. The excess water is pulled downwards. (superfluous water)
- Gradually, as the water content reduces, the force of attraction between clays and water is equal and the downward movement of water ceases. The soil is said to be at its field capacity.
- Crops growing on the soil absorb water and the negative potential gradually increases till it is equal to the force with which roots extract water from the soil. At this stage, roots cannot absorb any more water from the soil and crop wilts permanently. Soil moisture at this stage represents permanent wilting point.
- Water is lost continuously and the negative potential of water molecule increases until water vaporizes. The soil structure at this stage represents hygroscopic coefficient. (Fig 10.6).

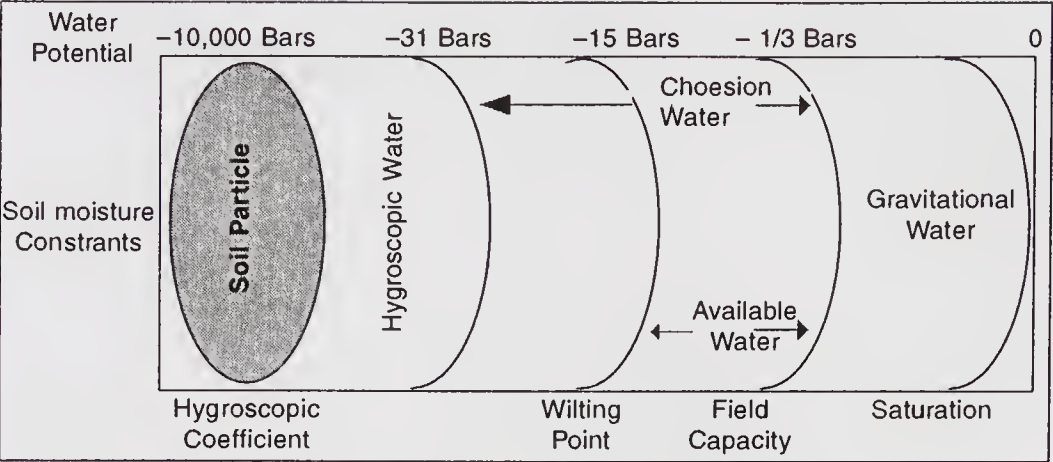


Fig 10.6. Moisture constants and soil water potential in bars

SOIL MOISTURE CONSTANTS AND THEIR RELANTIONSHIP

Saturation Percentage or Maximum Retentive Capacity

Saturation percentage is the water content of soil when all pores are filled with water. It is defined as the amount of moisture in a soil when its total pore spaces, both macro and micro are completely filled with water. Under these conditions, soil moisture tension is very low, between 1/100 to 1/1000 of an atmosphere or p^F is 1 or less. It is approximately double the field capacity value. Saturation percentage is approximately equal the water content of saturation paste prepared for analysis of soluble salts.

Field Capacity

Field capacity is the amount of moisture held by the soil after the excess gravitational water has drained away. This is the percentage of water remaining in a soil two or three days after its having been saturated and after free drainage has practically ceased. At this time water has moved out of the macro pores. The micro pores are still filled with water. At field capacity moisture tension is 1/3 atmosphere or 0.3 bar negative potential ($p^F=2.54$). Field capacity values are used to determine the amount of irrigation water needed and the amount of stored water available to plants.

Moisture Equivalent

The percentage of water retained by a previously saturated sample of soil 1 cm in thickness after it has been subjected to a centrifugal force 1000 times that of gravity for 30 minutes. The amount of moisture held at field capacity is approximately equal to the moisture equivalent. However, the relationship between field capacity and moisture equivalent is truer in case of moderately textured soils. The negative potential is approximately 0.5 bar and p^F value 2.7.

Wilting Coefficient

As plants absorb water from a soil, water is lost through evapo transpiration, i.e. evaporation and transpiration. As the soil dries out, plants begin to wilt and may remain in a permanent wilted condition. The wilting coefficient represents

Table 10.1. Classification of soil water

Type of classification and moisture tension		Categories of classifications		
i) Physical classification	Gravitational water	Capillary water		Hygroscopic
Negative potential	< 0.1 bar	0.1–31 bar		31–10,000 bar
ii) Biological classification	superfluous	Easily available	available with difficulty	Non available
Negative potential	< 0.1 bar	0.3–15 bar	15–31 bar	
iii) Classification according to	moisture holding capacity	Field moistur capacity	Wilting coefficient	31 bar
Moisture constants	capacity	equivalent	(non capillary)	Hygroscopic coefficient
Negative potential	< 0.1bar	0.3–15 bar	0.5–15 bars	
			15 bar	> 31 bar

the soil moisture content at which roots cannot take up water, and so the crop wilts. The negative potential or free energy of soil is approximately 15 bars. p^F value is 4.18.

Hygroscopic Coefficient

The percentage of moisture in a dry soil, when in equilibrium with an atmosphere saturated with water vapor (100 per cent humidity) expressed on oven dry basis is known as hygroscopic coefficient of soil.

As the soil moisture is lowered below the wilting point, the water molecules that remain are held very tightly. The water is held so tightly that it is considered non liquid and can move only in the vapor phase. Negative potential or free energy of soil water is approximately 31 bar and p^F value is 4.5.

A comparison between physical and biological classification of soil water with soil moisture constants is presented in Table 10.1.

Relationship Between Moisture Constants

Soil moisture constants are related to one another and are expressions of the ability of soil to retain water. The ability to retain water is related to soil separates sand, silt and clay. Thus soil moisture constants are related to soil texture as follows:

Hygroscopic Coefficient

= Wilting coefficient $\times$ 0.63

= Moisture equivalent $\times$ 0.37

= (Moisture holding capacity – 21) $\times$.0234

= 0.007 of % sand + 0.082 of % silt + 0.39 of % clay + organic matter

Moisture equivalent

= (Moisture holding capacity– 21) $\times$ 0.635

= Hygroscopic coefficient $\times$ 2.71

= Wilting coefficient $\times$ 1.84

= 0.02 of % sand + 0.022 of % silt + 1.05 of % clay

Wilting coefficient

= Hygroscopic coefficient / 0.68

$$\begin{aligned}
 &= \text{Moisture equivalent} / 1.84 \\
 &= \text{Moisture holding capacity} / 2.9 \\
 &= 0.01 \text{ of } \% \text{ sand} + 0.12 \text{ of } \% \text{ silt} + 0.57 \text{ of } \% \text{ clay}
 \end{aligned}$$

These values hold good for average of a large number of samples. Individual soils may show wide variations.

Soil Moisture Calculation

Moisture content should be calculated on the volume basis because (i) water is retained in the soil within a given volume (ii) It helps in the calculations of moisture held by soil in terms of inches per foot or centimeters per meter of water in the field. Thus, it has practical utility for water management in soils.

Data on percentage soil moisture on weight basis as obtained in the laboratory or field analysis may be utilized for practical use as follows:

% moisture by weight $\times$ bulk density = % moisture by volume.

For example, a soil of 6" (15 cm) depth with 25% moisture content by weight and a bulk density of 1.3 will have moisture content

$$25/100 \times 1.3/1 \times 9/1 = 2.92 \text{ area inches/9" depth of soil}$$

If values for maximum water holding capacity, field capacity, wilting point and bulk density of a soil are known, values of practical utility can be obtained about moisture characteristics of a soil.

Example: A soil has the following values for an acre foot depth.

- i) Maximum water holding capacity = 38%
- ii) Field capacity (1/3 atmosphere or negative potential 0.3 bar) = 20%
- iii) Wilting point (15 atmosphere or negative potential 15 bar) = 8%
- iv) Bulk density = 1.3 Mg/m³
 - a) At maximum water holding capacity, this soil will retain water
Maximum water holding capacity $\times$ Bulk density $\times$ 12
 $0.45 \times 1.3 \times 12 = 7.02$ inches/acre foot of soil
 - b) The water that can be lost through drainage, is the difference between maximum water holding capacity and field capacity
(38–20 = 18%)
 $0.18 \times 1.3 \times 12 = 2.808$ inches/acre foot of soil
 - c) Available water for plant growth, is the difference between field capacity and wilting point.
(20–8 = 12%),
 $0.12 \times 1.3 \times 12 = 1.872$ inches/ acre foot of soil
 - d) Unavailable water, as represented by wilting point (8%) will be;
 $0.08 \times 1.3 \times 12 = 1.248$ inches/ acre foot of soil

MEASUREMENT OF SOIL WATER CONTENT

A tendency to over or under irrigate results due to the absence of information about the soil moisture status down the soil profile. Monitoring the soil moisture is the principal fact to develop water management program to optimise plant growth and yield. There are many and varied methods for determining soil water content on a volume basis/tension basis.

Gravimetric Method

It measures water content of soil. Moist soil is oven dried to constant weight at 105°C for 24 hours. It is expressed as per cent of oven dry soil.

$$\text{Per cent moisture} = \frac{\text{Loss in weight}}{\text{Oven dry weight}} \times \frac{100}{1}$$

The water content on mass basis can be converted into volume basis by multiplying with bulk density.

For irrigation purposes, it is much more useful to express the water content on volume basis. This is expressed as the ratio of the volume of water to the volume of soil or equivalent depth of water to some specific (unit) depth of soil. Here, the soil sample is collected from the field in a special container of known volume. Core samples of known volume are used. The soil is weighed wet and the water content is determined gravimetrically. The volumetric water content, θ_v or depth of water, θ_d , are then calculated as follows:

$$\theta_v = \frac{P}{P_w} \theta_w \quad \theta_d = \theta_v \times L$$

Where P_w = density of water g cm³
 P = bulk density of soil sample g cm³,
 L = depth or length of soil sample

Bulk density values obtained from independent measurements in the same area can also be used for converting the water content on a weight basis to that on a volume basis.

For irrigation purposes the estimate of water content in the soil profile is needed to determine the profile soil water depletion. This is calculated by determining the volumetric water content n , the different depth increments of the profile using the following equation:

$$\theta_p = \sum_{i=1}^n \theta_{vi} L_i$$

Where θ_p = Profile water content, cm;
 θ_{vi} = average volumetric water content of the i th depth cm³
 L_i = length of the i th depth, cm;
 n = number of increments into which the profile has been divided.

The gravimetric method has several advantages. It is the most accurate of all methods presently in use. The results are not affected by the presence of salts in the soil sample. No complicated equipment is required and the procedure is very simple.

This method, however, suffers from several limitations. It is laborious and time consuming as it involves sampling from the field, transporting, drying, and repeated weighing. The sampling may cause considerable error depending upon the field variability. The water content values for stony or gravelly soil can be misleading as rock fragment contribute on to mass and volume and not to pore space.

Resistance Method

This is based on the principle that electrical resistance of certain porous materials such as gypsum, nylon and fiberglass is related to their water content. After being calibrated in the laboratory, blocks of materials such as gypsum are placed in moist soil in the field. These blocks absorb water, when equilibrium is reached, the electrical resistance is read. This resistance gives the measure of the water absorbed. This method is suitable for measurement of moisture in the field.

Nylon or fiberglass does not deteriorate in the soil whereas gypsum blocks are more sensitive to these variations. These electrical measurements are affected by the salt concentration in the soil solution. The gypsum blocks are less affected by the presence of salts as compared to nylon or fiberglass blocks.

Neutron Scattering Method

The most advance-developed technique of determining soil moisture is the so-called neutron scattering method. This is used for measurement of moisture *in situ* (in the field). The instrument is known as neutron moisture meter. This is based on the principle that hydrogen atoms (constituent of soil water) have the ability to drastically reduce the speed of the fast moving neutron. Thus fast neutron are emitted in the soil where they colloid with proton nuclei of water (that is, hydrogen). Neutrons in this state are called slow neutrons, which can be detected with the help of a scale or meter. The density of slow neutrons so formed around the source is nearly proportional to the concentration of hydrogen in the soil, i.e. proportional to the volume fraction of water present in the soil. These meters give accurate results in mineral soils where water is the main source of combined hydrogen. In organic soils since some of the hydrogen is combined with organic substances, this method may not be suitable. For irrigation scheduling water is the only form of H^+ that will change from measurement to measurement. Therefore any change in counts recorded by NP is due to a change in the moisture with an increase in counts relating to an increase in moisture content.

For field use aluminium tubes are inserted into the soil and stopped to minimise water entry. Readings are taken at depths down the profile (e.g. 20 cm, 30 cm, 40 cm, 50 cm, 60 cm, 80 cm, 100 cm and 120 cm) with a sixteen-second count. Three aluminium tubes are average to read one site and utilised for appropriate irrigation management. Measurements are taken two to four time a week and information is downloaded to a personal computer for interpretation.

Advantages of Neutron Scattering Method

(1) The measurement is not affected by salt content, soil texture and structure variations and of soil temperature variations. (2) It is sensitive over the entire range of available soil moisture and provides a direct measure of water content by volume with the help of a suitable calibration curve. (3) Generally the calibration curve supplied with the equipment is adequate. But under certain conditions like change in access tube or unusual neutron absorption, fresh calibration may be required. Accurate calibration curves require the use of a large homogeneous body of soil with a constant and uniform water content. (4) The field installations involve minimum soil disturbance and repeated readings are

possible without disturbing the experimental area. The measurements are rapid and equilibrium time between the soil and the instrument is small.

Limitations of Neutron Scattering Method

(1) The main disadvantage of the method is with regard to the initial cost of the equipment, which is very high. (2) It is not advisable to measure soil moisture of surface soil (less than 20 cm) with this equipment because of radiation hazards. (3) Because of the radioactive source, the instrument is to be handled carefully.

Time-Domain Reflectometry (TDR)

The technique is based upon cable testing technology, with a broadband electromagnetic (EM) step pulse generated and propagated along a coaxial cable. At the end of the cable stainless steel rods (wave guides) are inserted into the ground.

Measurement of Soil Moisture Tension, Use of Tensiometers

Tensiometers act in a similar principle to a plant root measuring the force that plants have to exert to obtain moisture from the soil. The tension with which water is held in soils is an indication of soil water potential. Tensiometer measures the tenacity with which water is held in soil. It consists of a porous cup filled with water and is placed in a soil. The cup is attached to a mercury manometer. As the soil dries out, water leaves the cell and enters the soil and the mercury rises in the manometer. As the soil becomes wet, water enters the cup again, which causes the mercury in the manometer to fall. Soil pulls the water from the cup, which in turn pulls up the mercury in the manometer. After equilibrium is established, the height of the column of the mercury measures the force or tenacity, with which water is held in a particular soil (Fig. 10.7). Thus the changes in soil moisture content is measured by the change in the height of the mercury column in the manometer.

Limitations in the Use of Tensiometers

- The tensiometers can not be employed at tension greater than one atmosphere. This may be partly due to the failure of the water column to withstand tensions above one atmosphere and also due to the vacuum gauge used which measures the partial vacuum relative to the external atmospheric pressure. The low air entry value of the ceramic cup also restricts its use above one atmosphere. Normally, the tensiometers measure about 0.85 bar of maximal suction.
- Tensiometers must be installed correctly and well maintained to operate accurately. Tensiometers may be placed permanently in the soil giving an analogue or digital output. Portable tensiometers allow greater freedom of sampling giving relatively quick reading of soil moisture tension.
- The tensiometers may not respond to the changes in the soil suction as fast they occur. The tensiometer readings are registered only when the hydraulic contact is established and equilibrium with the water in the soil has been reached. Thus, the tensiometer response may lag behind suction changes in the soil due to cup and instrument characteristics.
- In tensiometers made of metal or even plastic, the temperature affects the

measurement. The heat conduction through the main stem of the tensiometer from the portion above ground to the cup in the soil causes error in suction readings.

- Since the tensiometer measures only the soil moisture suction, calibration is needed for indicating the soil moisture content. All tensiometers require constant care and maintenance, especially the mercury manometer type.

Advantages of Tensiometer

- This method provides a direct measurement of the soil moisture tension below 1 bar and the measurement is not affected by the salt content of the soil.
- It is a direct reading instrument and no electrical units or meters are required.
- Tensiometers are commercially available and their installation is easy.
- They provide reliable information on the insitu state of the soil moisture profile and a guide to the scheduling of irrigation.

Expression of Soil Moisture Tension

The net pull or attraction, which holds the soil water on the surface and in the capillaries provided by soil particles, is called tension. The tension with which soil moisture is retained is expressed as centimeters of water, that is, the height of column of water in centimeters that would be required to exert enough force in terms of tension to remove water from soil at a given moisture content. In the drier ranges, all the moisture is held in the soil at tensions equal to millions of centimeters of water, the tension is converted to atmospheres of p^F values.

Atmosphere or Pressure

Moisture tension is expressed in terms of height in centimeters of a column of water one square centimeter cross-sectional area, whose length is equal to the negative potential or tension of soil water. The unit of soil moisture tension is defined as the force per unit area that must be exerted to remove water from soil. Since force per unit area is pressure, soil moisture tension is expressed in atmosphere. One atmosphere of tension means that the force holding the water is equal to about 1036 cm of water column height or a p^F value of 3. The unit term bar is equal to 1 atmosphere. One millibar is 1/1000 bar. 10 bar is equal to 1 megapascal (MPa). Other equivalents of atmosphere are:

1 atmosphere = 1 bar = 1036 cm of water = 76 cm of mercury = 14.7 lb/sq. inch

Energy Values (p^F)

The energy values are expressed as the logarithms of the tension of centimeters of a column of water. This value is called p^F , similar to the pH of hydrogen in concentration. p^F is the logarithm to the base ten of the height in cm. of a water column, 1 sq.cm, cross-sectional area whose weight is just equal to the negative potential or tension of soil water. p indicates logarithmic value and F as free energy. Thus the tension equivalent to a column of 10 cm. of water correspond to a $p^F=1$, of 100 cm. $p^F=2$ and so on.

The relationship between p^F height of water, atmosphere of pressure and soil water condition is given in Table 10.2.

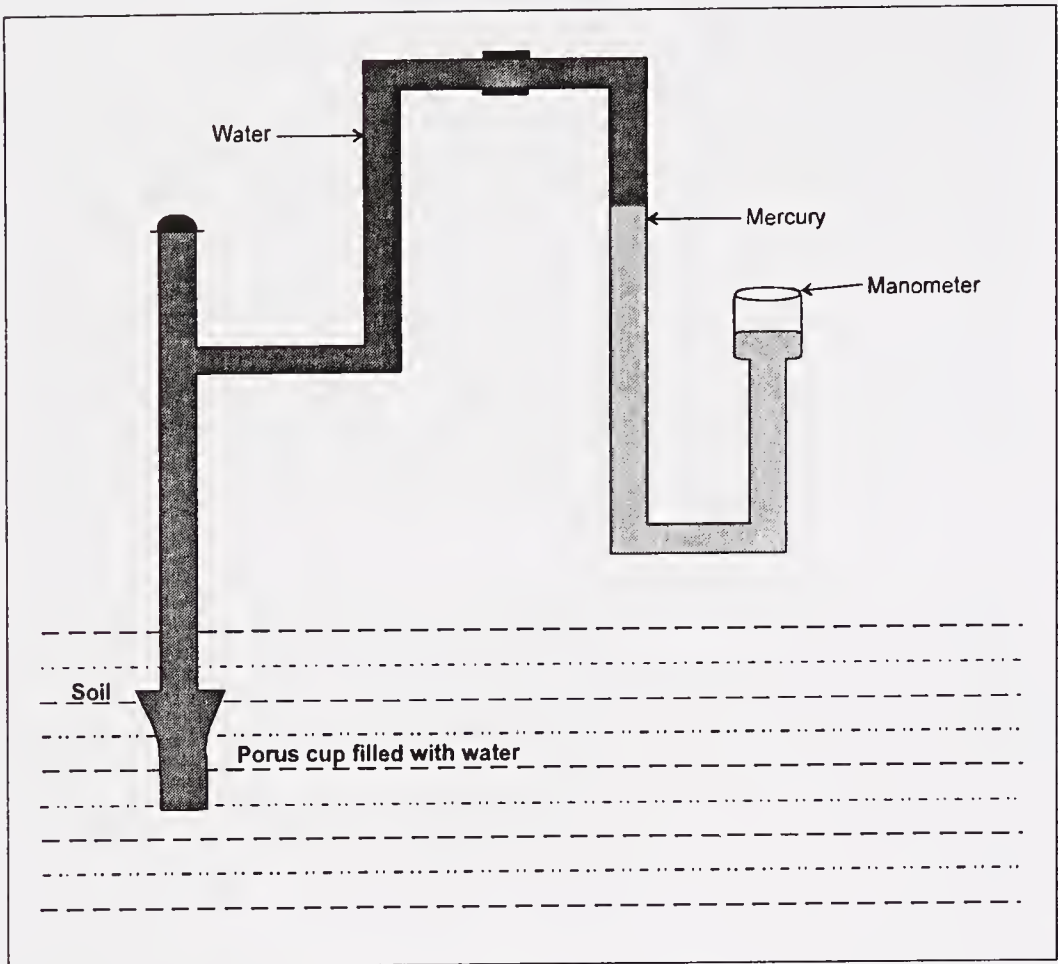


Fig. 10.7. Soil moisture tensiometer

Moisture Tension Data of Different Soils

Soil moisture tension data have been determined at different moisture range for a number of soils. If the moisture tensions are plotted against moisture contents, a curve is obtained which characterizes the moisture relationships for that soil. Typical moisture curves for sandy, loamy, and clayey soils are shown in Fig 10.8.

Following Inference can be Drawn from Moisture Tension Curves

- The tension values indicate the suction pressures that must be applied to extract water from soils containing varying amounts of water. At low, moisture contents, the soil holds the water with tremendous tenacity as much as 10,000 atmospheres. But when well supplied with water, the tension with which water is held by soil is lowered.
- The curves also show that at the same moisture content, water is held at higher tension in the heavier soils. At equivalent tensions more water is held in the heavier soils. However, continuous nature of soil moisture tension should always be kept in mind. A very thin film of water may be held at a tension of 10,000 atmospheres. But the same film, if thickened, the water in this thicker film is subject to less tension and can therefore be easily extracted.

Table 10.2. A comparison between p^F and atmosphere of pressure with soil moisture condition

p^F	Height of water (in cms)	Atmosphere of pressure	Soil water condition
0	1	1/1000	Saturated soil
1	10	1/100	
2	100	1/10	
2.54		0.3	Field capacity
2.7		0.33	Moisture equivalent
3	1000	1	Permanent wilting %
4	10000	10	
4.2		15	
5	100000	100	Oven dry condition
6	1000000	1000	
7	10000000	10000	

Available Water

Because water present in the root zone of a soil in excess of field capacity moves out of this zone quite rapidly, it may be available to plants for only a short period. Therefore, it is the water held between field capacity and the permanent wilting percentage that is generally considered to be available soil water. At water content near field capacity, relatively large amount of water may be extracted

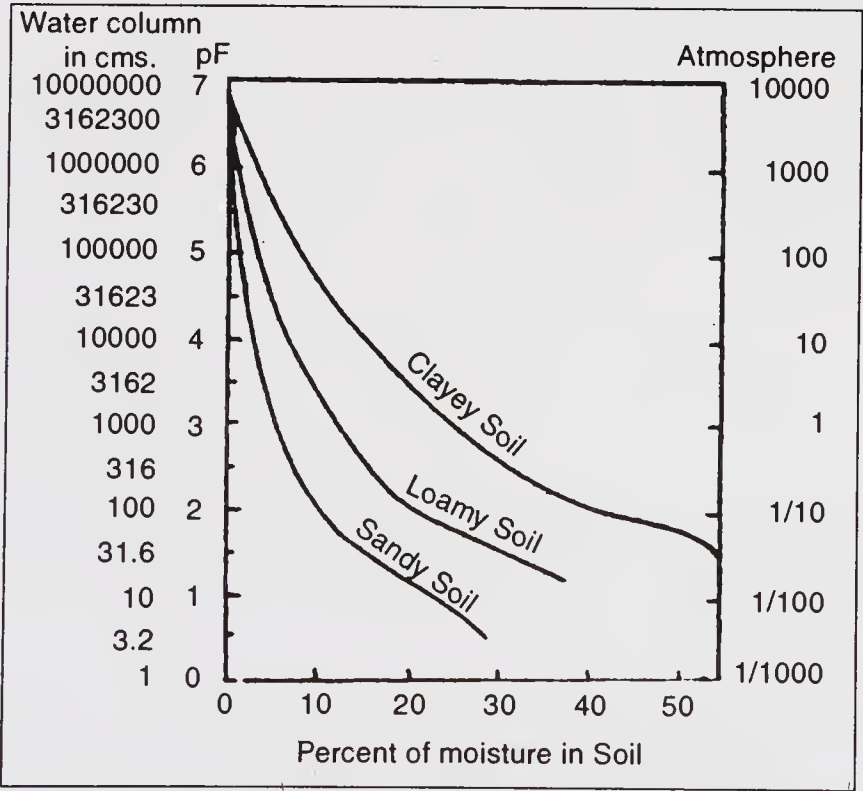


Fig. 10.8. Generalised moisture tension curves for clayey, loamy and sandy textural soils

with only moderate increases in tension. However, near permanent wilting percentage, a further decrease in soil moisture is accompanied by a large increase in tension at which, the remaining water is held. It is for this reason that even though some plants may exert a greater absorptive tension on the soil water than other plants, all of them have practically the same wilting point.

The most favorable moisture condition in the soil for the growth of plants, for good soil aeration and also for greater activities of micro-organisms, is near about p^F 2.7. Such optimum content of soil moisture is not definite with regard to percentage of water, but represents a zone of moisture limited by wilting coefficient and field capacity.

MOVEMENT OF WATER IN SOILS

Soil water movement will occur when there is a potential difference between different points in the soil system. The water moves from a zone of higher moisture potential to lower moisture potential. The movement of water in soil can be grouped in three categories: 1). Saturated flow 2). Unsaturated flow 3). Water vapour movement

Saturated flow

When almost all pores are filled with water. Water in this condition is tension free. Gravity and hydraulic conductivity determine the flow of water under saturated conditions.

Hydraulic conductivity can be expressed as, $V = kf$

Where V is the total volume of water moved per unit time

f = Gravitational force

k = the hydraulic conductivity; usually constant under saturated conditions. The movement of water depends on the hydraulic gradient.

Hydraulic gradient: The difference in height of water above and below the soil column. Saturated flow includes downward and horizontal movement of water.

Darcy's law: Darcy (1856) established the empirical relationship for flow of water through fine grained soils. Darcy's law indicates that the velocity of water through soil is proportional to the first power of the hydraulic gradient. It presents a mathematical expression for the vertical water flow rate. It states that the rate of flow (Q_w) was increased with an increased depth of water (dW) and the soil area through which it flowed (A). The flow decreased with an increased depth of soil (d_s) through which the water flow. The flow rate constant (k) varied for each soil owing to different pore sizes and number. Because the flow is downward water losses potential, the downward values are negative, Darcy's equation may be written:

$$Q_w = -k \frac{(dw) At}{D_s}$$

Where, Q_w = Quantity of water in cm^3

k = rate constant in cm/s .

dw = height of water in cm.

$$\text{or } k = \frac{-Q_w (ds)}{A t (dw)}$$

Where A = area of soil in cm^2

t = time (in sec.)

ds = Depth of soil in cm.

According to Darcy's law, the rate of percolation of water through a saturated soil is directly proportional to the pressure head and inversely proportional to the length of the column. $V = kh F/l$, where V is the velocity in ml. per second, h is the pressure in cm., l is the length of the column in cm., F is the area in sq.cm. , k is the proportionally constant.

When h, l and f are all unity, $V = K$. It is known as the coefficient of permeability. The equation is used to compare the permeability of soil samples in small cylinders in the laboratory. The cylinders are uniformly filled with soils and the amount of water percolating through, at a constant head is measured.

Darcy's law is valid only for those soils and under those conditions for which the flow is laminar and in which the pore spaces are capillary tubes. Darcy's law is not valid for very coarse, grained soils, which leads to the conclusion that the flow through soils is not laminar or that the tubes are not capillaries. Darcy's law does apply to all soils, except the very coarse grained ones, such as very coarse sand.

Factors Affecting Saturated Flow of Water

Texture: The total flow rate in soil pores is proportional to the fourth power of the radius. Thus, flow through a pore 1mm in radius is equivalent to that in 10,000 pores with a radius of 0.1 mm. Thus, macro pores account for most of the saturated flow. Thus, coarse textured soils have higher saturated conductivity than fine textured soils.

- **Structure:** Soils with stable aggregates conduct water rapidly than unstable structural units. Thus soils with granular structure have better water conductivity than those having platy or prismatic structure.
- **Organic matter:** Organic matter helps to maintain stable aggregates. Organic matter increases macro pores in clayey soils, micro pores in sandy soils. Thus it increases the saturated flow of water.
- **Types of clay:** Soils high in montmorillonite (2:1) generally have low conductivity as compared to soils with kaolinite (1:1) type of clays. This is because soils with 2:1 clays have a tendency for 'puddling' during wet periods and 'cracking' during dry periods. This adversely affects flow of water.

Unsaturated Flow in Soils

When soil pores are partially filled with water and air the water is under tension. Water in unsaturated soil exhibit very little tendency to move. Movement of water is mainly by adjustment of the thickness of water films on soil particles. Water occurs as surface films and as wedge in the angles of the adjoining soil

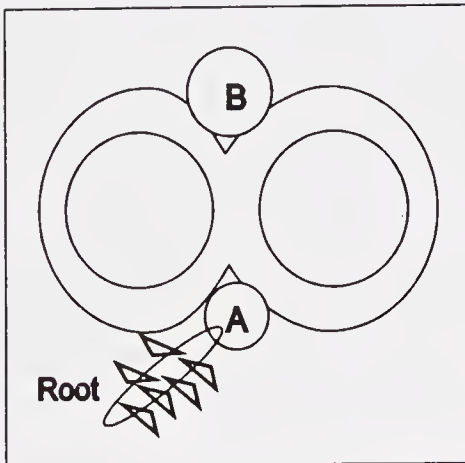


Fig. 10.9. Moisture films between two soil particles

particles as shown in Fig 10.9. There is a tendency to form spherical droplet at points A and B as shown in Fig. 10.9. However, droplet formation is prevented because two particle surfaces are acting against each other and curvature of films A and B become equal. We can explain movement of water in unsaturated soils in the direction of drier soils as a result of absorption of water by plant roots. The force tending to draw water into a given portion of the film varies inversely with the radius of the curvature $p = 2T/r$ where, p is pulling power, T is the surface tension and r is the radius of the curvature.

General relationship between matric potential and hydraulic conductivity for a sandy soil and a clay soil is shown in Fig 10.10.

From the Above, Following Conclusions can be Drawn

- Higher hydraulic conductivity values occur at zero potential as in saturated flow as compared to unsaturated flow (0.1 bar or less).
- At high moisture contents, hydraulic conductivity is higher in the sand than in the clay. In contrast to this, at low moisture contents, clay conducts more water than sand. This is expected since the dominance of large pores in the coarse textured soil encourage saturated flow whereas finer pores in the clay encourage more unsaturated flow than in the sand. Thus, movement of water will be from thick moisture films (higher matric potential) to one of thin films (lower matric potential).
- Water movement in soil is affected by matric potential gradient. In a study of movement of water from moist to dry soil it was found that water moves rapidly from the sample with higher moisture content. This is because when the water content in the moist soil is higher, the matric potential gradient between the moist and dry soil is also greater. Thus, more rapids are the flow.
- Under stressed conditions the rate of water uptake is greatly influenced by hydraulic conductivity of the soil.

Water Vapour Movement

Diffusion: Water vapor moves by diffusion as a result of differences in vapor pressure.

Mass flow: Water vapor flow in a mass with the other gases of the system. The flow is in response to differences in total pressure.

Effect of Moisture and Temperature on Movement of Water Vapour in Soil

- When soil moisture is at wilting coefficient capillary movement of water ceases. Thus at low moisture contents, water movement in soil can be only in the vapour phase.

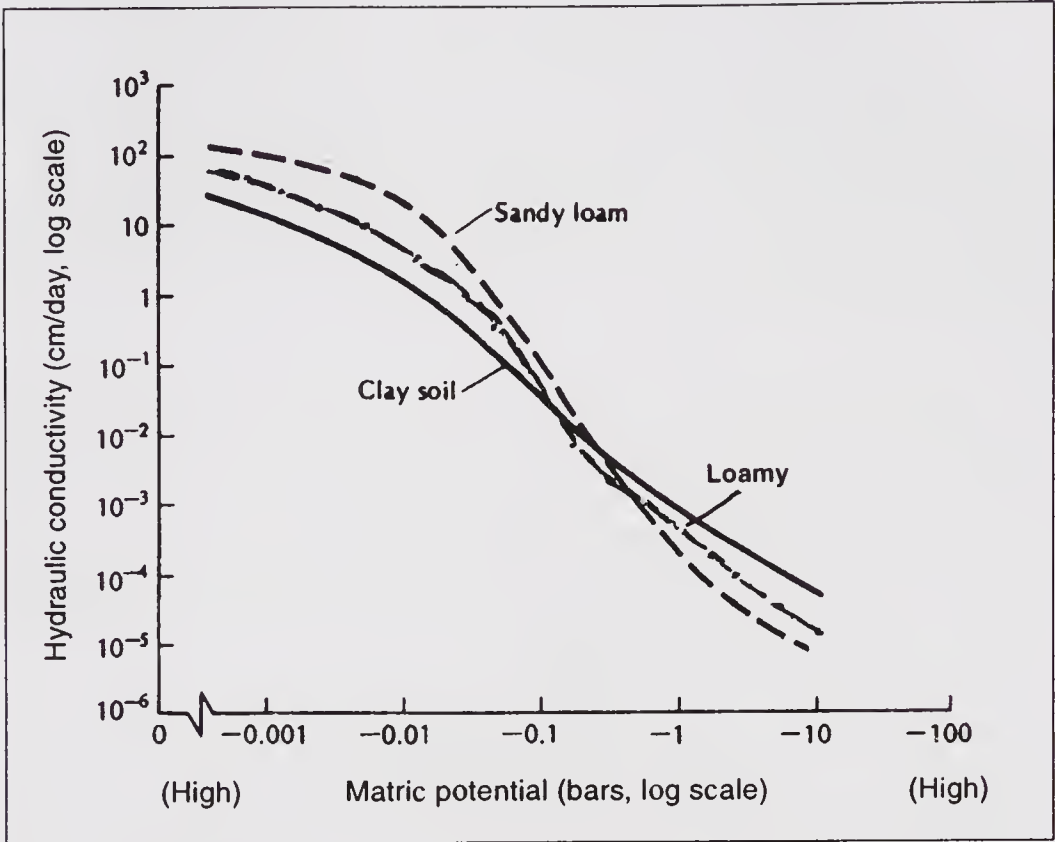


Fig. 10.10. Relationship between matric potential and hydraulic conductivity for a sandy loam, loam and a clay soil

- Soil air is saturated with water vapour. Thus at constant temperature vapour pressure of the water vapour in the soil air is constant and independent of the wetness of the soil at all moisture contents above the wilting point. But if the temperature varies, the vapour pressure rises with temperature.
- Moisture and water vapour will be transferred from the warmer point with higher vapour pressure and condense as water at the cooler point with lower vapour pressure.
- A diffusion of water vapour between different parts of the soil is initiated through vapour pressure gradients brought about by fluctuations in temperature. Water vapour will thus distil downwards when the surface soil is warmer as in summer and upwards when the subsoil is warmer as in winter. During summer, several centimeters of surface soil become dry. This is due to downward distillation and evaporation.
- In arid regions water vapour may condense into the soil from the overlying cool air and will be of help to the growing plants. Sometimes, when the atmospheric temperature rises, it is noticed that there is a sudden increase in the drainage flow of water from soils. This is due to the increased mobility of water at the higher temperature and due to the warmth of the air that causes water in the surface soil to vaporize and distil downwards to the cooler layers below.

PERMEABILITY

Permeability is the ease with which air, water and plant roots can pass through a soil material. In other words, permeability is the ability of the soil to transmit water or air. Permeability is commonly measured in terms of the rate of flow of water through the soil in a given period of time. The soil characteristics that determine the rate of movement of water down into the soil is called the hydraulic conductivity of the soil.

Factors Affecting Soil Permeability

Climate: Soil permeability depends upon the climate, particularly rainfall and topography of the area, because it is related to likelihood of running water. Soils having high permeability will not allow much runoff.

Soil texture: Permeability and hydraulic conductivity of soils depend mainly on the macro pores (non-capillary pores) in the soil. The number of macro pores depends on the texture and hence permeability depends on texture. Permeability increases with coarseness of soil texture.

Depth of the soil: The permeability of soil usually decreases with depth of the soil. This is because (a) subsoil layers are more compact, which reduces macro pores. (b) Organic matter content decreases with depth, which is an important contributing factor for good soil aggregation. (c) Presence of clay pans, hard pan decreases soil permeability.

Salts in irrigation water: Concentration and composition of dissolved salts dissolved in irrigation water affect permeability of the soil. Presence of sodium salts causes dispersion and reduces permeability.

Tillage practices: Permeability can be controlled by suitable management practices. Continuous tillage reduces permeability, thus to maintain moderate permeability optimum tillage should be adopted. Cultivation of legumes, and deep-rooted grasses increases permeability.

The presence of micro pores which is responsible for water retention and macro pores which are necessary for adequate water and air movement; in optimum ratio is the best of combination. This is met in medium-textured soils such as loam, sandy clay loam or clay loam.

Table 10.3. Relative classes of soil permeability

Set of class	Permeability class	Inches per hour	Cms per hour
Slow	Very slow	< 0.05	< 0.127
	Slow	0.05 – 0.20	0.127 – 0.508
Moderate	Moderate slow	0.20 – 0.80	0.508 – 2.032
	Moderate	0.80 – 2.50	2.032 – 6.350
	Moderate rapid	2.50 – 5.00	6.350 – 12.700
Rapid	Rapid	5.00 – 10.00	12.700 – 25.400
	Very rapid	> 10	> 25.400

Table 10.4. Infiltration classes.

Infiltration class	Rate of Infiltration		Nature of soil
	Inches/hour	Cm/hour	
Very slow	< 0.1	< 0.254	High in clay
Slow	0.1 to 0.5	0.254–1.27	High in clay and low in organic matter
Moderate	0.5 to 1.0	1.27 – 2.54	Sandy loam, silt loam, sandy clay loam
Rapid	> 1.0	> 2.54	Well-aggregated soils Sandy soils.

Permeability Classes

Permeability classes may be slow, moderate and rapid. (Table 10.3).

INFILTRATION

The downward entry of water into the soil is called infiltration. Infiltration rate describes the maximum rate at which water can enter the soil under specified conditions. Percolation, is the movement of water through a column of soil under saturated conditions. Percolation causes loss of nutrients through leaching.

Factors Affecting Infiltration

Surface soil: A compact surface permits less infiltration. A loose porous well-aggregated surface soil allows more water to infiltrate.

Texture: Initially infiltration is high in a clayey soil. On swelling of clays, cracks are closed and infiltration is reduced.

Cultivation: Excessive tillage, which causes compactness of surface layers, reduces infiltration. A practice that loosens the surface soil increases infiltration.

Wetness: In general, infiltration rate is lower in wet soils than in moist or dry soils. After the soil becomes saturated, further infiltration rate depends on the percolation rate. Infiltration classes are shown in Table 10.4.

References and Suggested Readings

Foth, H.D. and Turk, L.M. (1973). *Fundamentals of Soil Science*. Wiley Eastern Pvt. Ltd., New Delhi.

Mehra, R.K. and Lavti, D.L. (1989). *Departmental and Research Report on Physical Properties of Soils*. Rajasthan College of Agriculture, M.P. University of Agriculture and Technology. Udaipur.

Ram Dev (1996). *Advanced techniques of Soil Moisture Monitoring*. Paper presented in the summer institute May 16-20, 1998, M.P. University of Agriculture. & Technology, Udaipur.

Richards, L.A. (1965). Physical condition of water in soil, in Agron 9 : *Methods of Soil Analysis, Part I* (Madison, WI. : American Society of Agronomy.

QUESTIONS

Q. 1. Fill in the blanks

- i) The water pressure in a capillary tube is less than zero or _____.
- ii) The height of rise in a capillary tube is inversely proportional to the _____ of the tube and directly proportional to the _____.
- iii) The soil water containing nutrient ions is known as _____.
- iv) Gravitational water is held by soil with a force of less than _____ bar.
- v) Capillary water is held in micropores at tensions between 0.1 to _____ bars.
- vi) Hygroscopic water is held with a force between _____ to bars. This is mostly non liquid.
- vii) Water retained between the _____ and the wilting coefficient is called available water.
- viii) Water held at a potential more than _____ atmosphere is called unavailable water.
- ix) _____ and osmotic potential are always negative.
- x) The unit term _____ is equal to 1 atmosphere.
- xi) The thickness of the moisture film around the clay increases till it becomes _____.
- xii) At saturation percentage, soil moisture is between _____ to _____ of an atmosphere.
- xiii) _____ is the amount of moisture held by the soil after the excess gravitational water has drained away.
- xiv) The amount of moisture held at field capacity is approximately equal to the _____.
- xv) Negative potential at hygroscopic coefficient is approximately _____ bar.
- xvi)
$$\% \text{ moisture} = \frac{\text{Loss in weight}}{(\quad)} \times \frac{100}{1}$$
- xvii) The _____ blocks are less affected by the presence of salts as compare to nylon or fiberglass blocks.
- xviii) Neutron scattering method is not suitable in _____ soils.

Answers

(i) Negative (ii) diameter, surface tension (iii) soil solution (iv) 0.1 (v) 31 (vi) 31 to 10,000 bars (vii) field capacity (viii) 15 (ix) matric (x) bar (xi) zero (xii) 1/100th to 1/1000th (xiii) field capacity (xiv) moisture equivalent (xv) 31 (xvi) oven dry weight (xvii) gypsum (xviii) organic.

Q. 2. Choose the correct answer

- i) In coarse textured soils the pores are non capillary/capillary.
- ii) Hygroscopic water is mostly in non liquid/ liquid form.

- iii) When soil water is absorbed by the clay particle, than its free energy is decreased/ increased.
- iv) Free energy is also called potential/ kinetic energy.
- v) At moisture equivalent the negative potential is approximately 0.5 bar/1 bar.
- vi) The macropores/ micropores account for most of the saturated flow
- vii) Coarse/ fine- textured soils have higher saturated conductivity.
- viii) Soils with montmorillonite generally have low/ high conductivity as compared to soils with kaolinite type of clays.
- ix) At low moisture contents, water movement in soil can be in vapor phase/ through diffusion.
- x) Soils with high permeability will not allow/ allow much run of .
- xi) Excessive tillage reduces/ increase infiltration.

Answers

(i) non capillary (ii) non liquid (iii) decreased (iv) potential (v) 0.5 bar (vi) macropores (vii) coarse (viii) low (ix) vapour phase (x) allow (xi) reduces.

Q. 3. Define the following

(i) Hydrogen bond (ii) Moisture tension (iii) pF (iv) Hydraulic gradient (v) soil permeability (vi) infiltration (vii) percolation

Q. 4. Differentiate between

- i) Adhesion water and Cohesion water.
- ii) Field capacity and Moisture equivalent.
- iii) pF and pH.
- iv) Saturated and unsaturated flow in soils .
- ii) Water vapor movement by diffusion and mass flow.

Q. 5. Write short notes on

(i) Structure of water (ii) Neutron scattering method (iii) Resistance method of measuring soil water content using gypsum block (iv) one atmosphere of tension (v) Darcy's law.

Q. 6. Comment on the following statements

- i) Water influences plant life.
- ii) Water molecules are highly polar.
- iii) Usually the height of rise resulting from capillary is greater with fine textured soils.
- iv) Difference in free energy levels from one point to another controls movement of soil water.
- v) Matric potential is always negative.
- (vi) Osmotic potential is always negative.
- vii) Field capacity values are used to determine the amount of irrigation water needed and the amount of stored water available to plants.
- viii) Some plants may exert a greater absorptive tension on the soil water than other plants, all of them have practically the same wilting point.

- ix) The most favorable moisture condition in the soil for the growth of plants is near pF 2.7.
- x) Water movement in soil is affected by matric potential gradient.
- xi) During summer, several centimeters of surface soil becomes dry.
- xii) When the atmospheric temperature rises, there is a sudden increase in the drainage flow of water from soils.
- xiii) Permeability depends on soils texture.
- xiv) The permeability of soil usually decreases with depth of the soil.

Q. 7. Answer the following in brief

- i) What is the significance of hydrogen bonding in water.
- ii) Write in brief about physical classification of water.
- iii) Enlist soil moisture constants.
- iv) What is meant by available water.

Q. 8. Answer the following in detail

- i) Explain the mechanism of water retention by soil.
- ii) Make a comparison of availability of water with regard to physical, biological classification and moisture constants.
- iii) Explain diagrammatically the measurement of soil moisture tension using tension meter.
- iv) Explain factors affecting saturated flow of water.
- v) Discuss factors affecting infiltration.

Q. 9. Give diagrammatic view of the following

- i) Types of soil water, water potential in bars and pore space at each constant.
- ii) The variations in moisture tension curves for different soil textured classes with varying moisture levels.
- iii) Moisture constants and soils water potential in bars.



11

Soil Air

THE pores that are not filled with water contain gases. Plant roots and organisms living in the soil uses oxygen from it. Plants carry on respiration, utilize energy and release carbon dioxide which can be shown in a generalized equation: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$

Under such conditions the soil air becomes depleted of oxygen and enriched with carbon dioxide. Excess of carbon dioxide is toxic to many plants. Hence, the rate of transfer of CO_2 from soil to the atmosphere and inturn that of oxygen from soil to the atmosphere is a main concern. The gaseous phase of the soil depends on its texture, structure and water content. Composition of atmospheric air and soil air is presented in Table 11.1.

COMPOSITION OF SOIL AIR AND FACTORS AFFECTING IT

Soil air contains about 5 to 10 times more carbon dioxide than the atmospheric air. The oxygen content is decreased in proportion to the increase of carbon dioxide. The composition of soil air is determined by the difference between the rate of production of carbon dioxide in the soil and its rate of removal. The carbon dioxide produced in the soil may be diffused into the atmosphere or lost into the deeper layer of soil by rainwater.

Factors affecting composition of soil air may be summarized as below:

Soil air content: When the air content of soil is less than 10%, the rate of gaseous exchange (production of CO_2 and its removal) falls, which results in an increase in carbon dioxide in soil air.

Soil compaction: Compact soils suffer from poor aeration. The air of sub soil contains more carbon dioxide and less oxygen than surface soil. Besides, soil layers may become dense to restrict the growth of roots.

Macro pores in soil: Macro pore content affects total air space, gaseous exchange and biochemical reactions. Soil texture, bulk density, aggregate stability and organic matter content determine macro pore content and thus soil aeration is

Table 11.1. Composition of atmospheric and soil air

	Per cent by volume		
	Nitrogen	Oxygen	CO_2
Atmospheric air	79	20.95	0.03
Soil air	79–80	18–20	0.15–0.3

simultaneously affected. The gaseous exchange is quite rapid in sandy soils having large pores, while it is slow in clay soil because their non-capillary pores are small in size.

Waterlogging: It affects gaseous diffusion. Since diffusion is related to the non-capillary pore space, such spaces are closed under waterlogging conditions. This increases concentration of carbon dioxide.

Organic matter: Presence of readily decomposable organic matter increases microbial activity. Thus production of carbon dioxide is enhanced. If gaseous exchange is not rapid to remove carbon dioxide from the soil air, its concentration increases.

Soil temperature and soil moisture: In general, higher temperature and higher soil moisture both increase production of carbon dioxide in soil air.

Soil heterogeneity: Poorly aerated pockets may be found in compacted or heavy textured soil layer. Thus, oxidation reactions may be occurring within a limited zone where reducing conditions exist. Heterogeneity of soil aeration may influence composition of soil air. The maintenance of crumb structure having large aggregates is of great importance. It facilitates the rapid movement of gases into and out of the soil pores.

Seasonal variation: In summers when the soils are drier, gaseous exchange is increased. This results in high oxygen and low CO₂ levels in soil. Since high temperatures encourage microbial decomposition of organic matter, such soils may have high CO₂ levels.

MECHANISM OF GASEOUS EXCHANGE

Two mechanisms have been proposed, i.e. Mass flow and Diffusion

Mass flow: Mass flow of air is due to pressure differences, i.e. from a zone of high pressure to a zone of low pressure. Thus, soil air gets mixed with the atmospheric air equalizing their compositions. This is affected by (i) Changes due to presence of water. Entry of water into the soil, forces air out of soil. Loss of water through evaporation or its consumption by plants provides way open for air. (ii) Gaseous exchange takes place due to temperature variations between soil surface and the atmosphere. (iii) Increase in pressure decreases volume of soil air. This leads to entry of atmospheric air into soil and *vice versa*. (iv) Wind influences gaseous exchange.

Diffusion: Diffusion is the molecular transfer of gases through porous media. Diffusion accounts for most of the gaseous interchange. According to this, gases in a mixture diffuse according to their individual partial pressures. The partial pressure of a gas, is the pressure, which this gas would exert if it alone were present in the volume occupied by the mixture. Thus 21% of oxygen in the air exerts a partial pressure of 0.21 atmosphere (–0.21 bar). Diffusion takes place continuously even if there is no pressure gradient. This is because soil air contains more CO₂ and a little less oxygen than the atmospheric air. Hence CO₂ moves out of the soil into the atmosphere and oxygen from the atmosphere moves into the soil. Thus equilibrium is established between the gases in soil air with those in the atmosphere. The pores larger than 15 microns, which control drainage water

mainly, contribute to the diffusion process.

The velocity of diffusion is inversely proportional to the square root of the density of the gas. The densities of CO₂, oxygen, nitrogen and water vapours response at N, T, P. are 1.98g, 1.43g, 1.25 g and 0.8g per litre. Therefore, CO₂ will have the slowest speed of diffusion from soil air to the atmosphere. The presence of macro pores, soil compaction and soil structure affect diffusion.

Fick's law: Diffusion of gases takes place under the concentration gradient. Thus,

$$q = -D \frac{dc}{dx}$$

Where q is the amount of gases diffusing in unit time across of a plane of unit area; D, the diffusion coefficient, is equal to q when dc/dx, concentration gradient, is unity. Since the gradient is in the direction of lower concentration, dc/dx is negative.

Measurement of Soil Aeration

Oxygen diffusion rate method

Oxygen diffusion rate (ODR) is the best measurement of the aeration status of the soil. ODR is determined by using the platinum microelectrode technique. Diffusing oxygen is allowed to reduce at the platinum electrode at a given electric potential. The rate of diffusion of O₂ to the platinum electrode is used as an index of the rate of diffusion of O₂ through the water films to the roots. The reaction in two different media are:

Acid medium $O_2 + 2H^+ + 2e^- = H_2O_2$

$H_2O_2 + 2H^+ + 2e^- = 2H_2O$

Neutral or $O_2 + 2H_2O + 2e^- = H_2O_2 + 2OH^-$

alkaline medium $H_2O_2 + 2H^+ + 2e^- = 2H_2O$

An electric current flows between the two electrodes and is proportional to the rate of oxygen reduction. The rate of oxygen reduction is in turn related to the rate at which it diffuses to the electrode (Fig. 11.1).

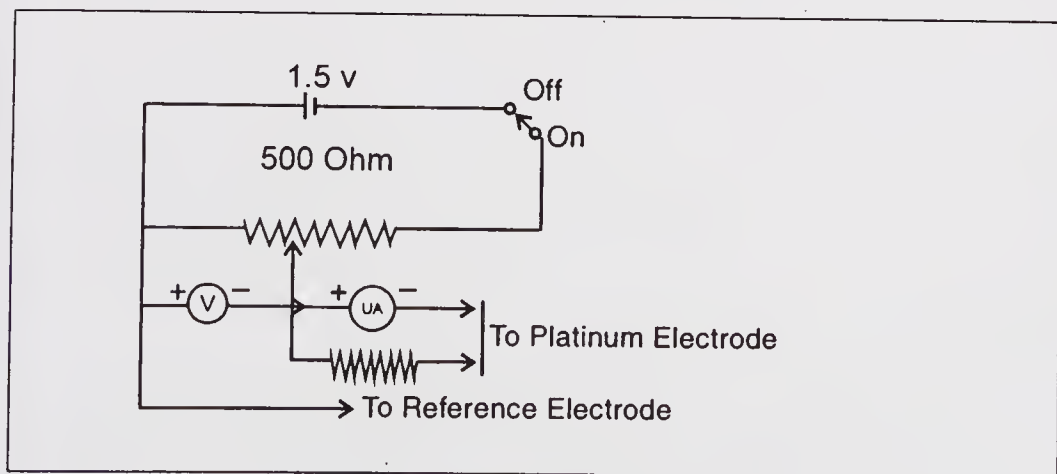


Fig. 11.1. Circuit diagram of ODR meter

Limitations in the Use of Platinum Microelectrodes in Soil

Standardization of method: The method should be standardized. It includes voltage to be applied (potential between 0.55 and 0.75 volt can be used for standard recommendation); time for which potential is applied (3–4 minutes are recommended for a steady state condition); the size of the electrode (25 gauge electrode is found to give accurate measurement of ODR over a greater moisture range).

Soil moisture: A thin film of water should cover the whole area of the electrode in the soil. The total surface area functions as a reducing surface when the entire electrode is wet. Theoretically, ODR increases with decreasing soil moisture. Variations may be found due to incomplete electrode wetting.

Temperature: An increase in temperature decreases the solubility of oxygen. The solubility of oxygen decreases approximately 1.6%/°c.

Poisoning: Sulphur compounds may poison the electrode. It reduces the sensitivity of electrode to reduce oxygen. Fresh electrode needs to be installed in such cases.

Soil Moisture Tension Method for Evaluating Soil Porosity

This method is not a direct measurement of air circulation in soils. The method of measuring aeration porosity involves allowing a saturated soil to drain under a specified tension. The volume of water that drains from the soil is taken as the volume of the aeration pore space. An equivalent to the tension that exists in a layer of soil located 40–60 cm above water table is used (equivalent to a column of water between 40–60 cm long).

Limitations of Soil Moisture Tension Method

- Some pores may be drained and yet remain isolated from the drained pores. As a result, the oxygen in these pores may soon become depleted and a condition of poor aeration may exist in spite of their presence.
- Total pore space cannot be considered as a suitable measure of aeration. Macro pores provide aeration capacity where as micro pores provide capillary porosity. The fine-textured soils have the highest percentage of total pore space but they hold most water and need maintenance for adequate aeration.

SOIL AIR IN RELATION TO PLANT GROWTH

Concentration of CO_2 in soil air in excess of 1% causes toxicity to most crop plants. Thus relative concentrations of CO_2 and oxygen in soil air is of significance from the point of view of most crops. This is summarized below:

Availability of water and nutrients: When oxygen is less in soil, plant roots are unable to extract more water and nutrients. Even under waterlogging conditions, plants may suffer shortage of water and nutrients, which they could not absorb due to lack of oxygen.

Oxygen Diffusion Rate (ODR): Oxygen diffusion rate (the rate at which oxygen in the soil exchanges with oxygen in the atmosphere), indicates the rate at which oxygen can be replenished when it is used by plant roots or by soil micro-organisms. Water can also force out oxygen. The rate of growth of roots of

Table 11.2. Oxidized and reduced forms of elements and their redox potential

Element	Oxidized form	Reduced form (Eh)	Redox potential
Oxygen	O ₂	H ₂ O	0.38 to 0.32
Nitrogen	NO ₃ ⁻	N ₂ , NH ₄ ⁺	0.28 to 0.22
Iron	Fe ³⁺	Fe ²⁺	0.18 to 0.15
Manganese	Mn ⁴⁺ (ic)	Mn ²⁺ (ous)	0.28 to 0.22
Sulphur	SO ₄ ²⁻	S ²⁻ , H ₂ S	-0.12 to -0.18
Carbon	CO ²	.CH ₄	-0.2 to 0.28

most plant ceases when the *oxygen* diffusion rate is below 20×10^{-8} g/cm²/ minute.

Effect on redox potential: Oxidation reduction (Redox) potential (Eh); provides a measure of the tendency of a system to reduce or oxidize elements. It is measured in volts or millivolts. If Eh is positive, strong oxidizing conditions exist. If Eh is negative, elements are found in reduced forms, which are toxic to plants. (Table 11.2). Soil air has an important role in oxidation reaction of iron and manganese. (i) Manganese exists in soil in several different stages of oxidation. It is most sensitive to changes due to variations in soil aeration. Manganese deficiency can be corrected by lowering soil pH or by subjecting soils to anaerobic conditions by water logging. In a similar way, manganese toxicity can be corrected by improving the oxidation condition in the soil by drainage or tillage operations. (ii) Iron is less stable in the reduced condition. Ferrous iron is unstable. Iron deficiency can also be corrected by aerobic condition. Many other chemical reactions are affected by soil aeration. (iii) When soil aeration is poor different compounds such as methane, hydrogen sulfide, aldehydes and ferrous iron are formed. (iv) Under anaerobic conditions oxidation of ammonia to nitrate does not take place. Hence, ammonia is accumulated. (v) Production of carbon dioxide is important in many ways (a) CO₂ increases the solubility of phosphate minerals (b) CO₂ is important in weathering of minerals in the soil (c) excess of CO₂ adversely affects seed germination, plant growth and production.

Soil aggregation: The failure of poorly aggregated soils to respond to fertilization may be because of deficient oxygen supply and low nutrient absorption.

Microbial activity: All aerobic organisms need oxygen to function properly. Under poor aeration condition only anaerobic and facultative micro-organisms can function. Root respiration is constrained under low oxygen levels a process that provides the energy for nutrient and water absorption. Thus plants growing on poorly drained soils may show nutrient deficiency symptoms even though the soils are well supplied with available nutrient elements.

Root growth and development: Aeration requirements for plants differ. Legumes are sensitive to poor aeration whereas grasses are tolerant. Development of roots requires oxygen. In general, with air capacity of less than 20% growth and development of plants may suffer. Root elongation is sensitive to aeration conditions. The water intake of plants decreases under poor aeration due to adverse effect of absorption of water by roots. A difference in the internal structure of roots is observed depending upon the status of aeration. Also differences in

anatomical and histological characteristics of roots of barley were noted as a result of variations in soil aeration. Aerated plants have a longer portion of root over which absorption of water and salts occur. Oxygen deficiency disturbs metabolic processes in plants, resulting in the accumulation of toxic substances in plants.

Incidence of diseases: Insufficient soil aeration is associated with the incidence of diseases in some crops. Wilt, a very common fungal disease of plants, is due to waterlogging of surface soils.

Accumulation of toxic substances: Poor aeration results in the development of toxins and other injurious substances such as dihydroxystearic acid. It leads to the accumulation of organic acids such as butyric, lactic, acetic etc. in toxic quantities.

Maintenance of Soil Aeration

In order to maintain proper aeration in relation to soil and crop management, following practices should be adopted.

Maintenance of soil moisture: Removal of excess quantities of water [adequate drainage] is necessary if sufficient oxygen is to be supplied. Control of soil moisture is necessary for better soil aeration.

Maintenance of stable aggregates: Maintenance of stable soil structure is important for augmenting good aeration (macro pores). This is done by maintenance of organic matter by addition of farmyard manure and crop residues.

Cultivation practices: Cultivation of heavy texture soils is an aid to soil aeration. Frequent light cultivation is good for crops with large taproots as this encourages soil aeration.

Selection of crops and their varieties: Selection of crops tolerant to low levels of oxygen: Shallow rooted plants such as grasses do well on poorly aerated soils. Rice plant flourishes even when the soil is submerged with water. Contrary to this, fruit and forest trees require deep, well-aerated soils.

Other Management Practices

- Improving soil structure. Granular and crumb structure increases macro pores. Thus addition of organic matter increase stability of aggregates.
- Adopting proper cultivation practices, light intercultural operations.
- Improving soil drainage will enhance gaseous exchange.

References and Suggested Readings

- Baver, L. D., Gardner (1976). *Soil Physics*. Wiley Eastern Ltd., New Delhi.
- Bear, F. (1964). *Chemistry of the Soil*, 2nd edn. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi.
- Hillel, D. (1982). *An Introduction to Soil Physics*. Academic Press, New York.
- Kohnke, H. (1968). *Soil Physics*. McGraw Hill Book Co., New York, USA.
- Miller, R.W. and Donahue, R.L. (1997). *Soils in our Environment*. Prentice Hall of India, New Delhi.
- Oswal, M.C. (1983). *A Textbook of Soil Physics*. Vikas Publishing House Pvt. Ltd., New Delhi.

QUESTIONS

Q. 1. Fill in the blanks

- i) Soil air contains _____ times more carbon dioxide than the atmospheric air.
- ii) The air of sub soil contains more carbon dioxide and less _____ than surface soil.
- iii) Presence of readily decomposable organic matter _____ microbial and production of CO_2 is _____.
- iv) _____ accounts for most of the gaseous interchange.
- v) Gases in a mixture diffuse according to their individual _____.
- vi) The diffusion is inversely proportional to the _____ of the density of the gas. Thus, CO_2 will have _____ speed of diffusion from soil air to the atmosphere.
- vii) Concentration of CO_2 in soil air in excess of 1 per cent causes _____ to most crop plants.
- viii) The rate of growth of most plant ceases when the oxygen diffusion rate (ODR) is below _____.

Answers

(i) 5 to 10 (ii) Oxygen (iii) increases, enhanced (iv) diffusion (v) partial pressure (vi) square root, slowest, (vii) toxicity, (viii) 20×10^{-8} gms/cm²/minute

Q. 2. Choose the correct answer

- i) When crops grow they increase / reduce the amount of carbon dioxide.
- ii) The carbon dioxide content of surface soil is more in warmer / cooler regions.
- iii) Improving soil drainage will enhance / lessen gaseous exchange.
- iv) Legumes are sensitive / tolerant to poor aeration.
- v) The diffusion is inversely / directly proportional to the square root of the density of the gas.
- vi) Diffusion / mass flow accounts for most of the gaseous interchange.

Answers

(I) increase (ii) warmer (iii) enhance (iv) sensitive (v) inversely (vi) diffusion

Q. 3. Define the following

- (i) Oxygen diffusion rate (ODR) (ii) oxidation-reduction potential.

Q. 4. Differentiate between

- i) Soil air and atmospheric air.
- ii) Transformation of manganese, iron and sulphur under reduced conditions.

Q. 5. Write short notes on

- (i) Mass flow (ii) Diffusion

Q. 6. Comment on the following statements

- i) The rate of transfer of CO_2 from the soil to the atmosphere and in turn that

of oxygen from the atmosphere to the soil is very important.

- ii) Diffusion takes place continuously even if there is no pressure gradient.
- iii) Even under water logging conditions plants may suffer shortage of water and nutrients.
- iv) Equilibrium is established between the gases in soil air and those in the atmosphere.

Q. 7. Answer the following in brief

- i) What is the fate of carbon dioxide produced in the soil?
- ii) What are the practices to be followed to maintain proper soil aeration in relation to soil and crop managements.

Q. 8. Answer the following in detail

- i) What is the importance of soil air in relation to plant growth.
- ii) Describe factors affecting composition of soil air.

Q. 9. Give diagrammatic view of the following

- i) Circuit diagram of ODR meter.



12

Soil Temperature

Soil temperature controls the physical, chemical and biological processes occurring in soil. Physical properties as affected by temperature fluctuations have their influence on plant growth. Low temperatures slow down processes like chemical reaction and biological decomposition. High temperature leads to dryness, as much of the sun's energy is left to heat the atmosphere, despite the heat dissipated by evaporation when surface soil moisture is high. All vital processes can continue with adequate intensity between a certain range of temperature from 5 to 50°C. Below or above this temperature range, life processes practically cease to function.

Heat energy is lost from the earth to space and is replaced by energy from the sun. The net heat absorbed by the earth equals the heat lost as far-infrared radiation. It can be depicted in the following equation:

$$R_N = R_S - R_R = G + H + LE = R_L$$

Where,

R_N ; net radiation

R_S ; incoming short-wave solar radiation

R_R ; reflected short-wave radiation

G ; heat absorbency by the ground

H ; heat absorbed by the air

LE ; latent heat (used to evaporate water)

R_L ; long-wave far-infrared radiation

Total solar energy falling on the earth is equivalent to 75,000 calories per square centimeters per year. Of the total energy received, 0.5% is recovered in the crop. Less than 10% of this or only 0.05% is perhaps recovered as food grains and fruits.

FACTORS INFLUENCING SOIL TEMPERATURE

Amount of solar energy: Soil derives its heat from the sun. However, oxidation of organic matter contributes a small amount of heat. The quantity of radiant energy reaching the soil depends on the (a) position of the sun, (b) the atmosphere (c) slope of the land (d) the vegetative cover and (e) the soil colour (f) depth and time of the day and (g) Nature of soil.

Position of the sun: In tropical areas, the sun is directly overhead. If atmosphere is cloud free, 75% of the solar radiation reaches the earth. There is an increase in soil temperature as one proceeds from the arctic to the equator. The amount of radiant energy received in the polar regions is much less than that in the equatorial belt as the angle of incidence is greater in the former latitudes. (Fig. 12.1).

The atmosphere: The longer the distance, sun's rays have to pass through the

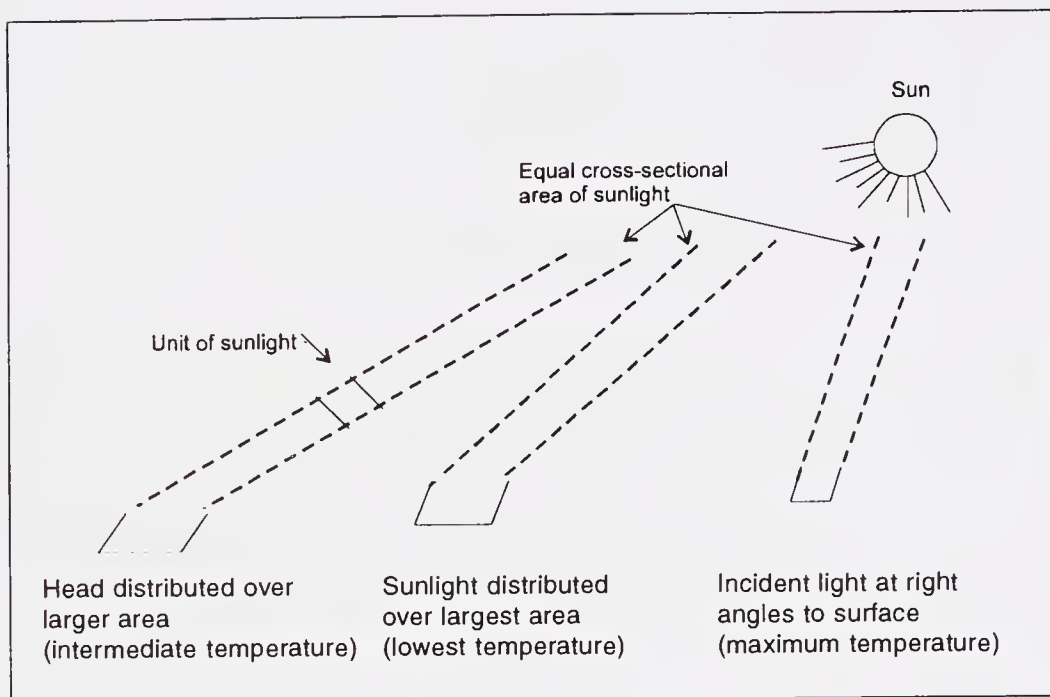


Fig. 12.1. Effect of slope, direction and the sun's position on the heat supplied to soil

atmosphere the greater is the absorption of heat by the atmosphere. Thus more heat reaches the earth during the afternoons when the sun is low in horizon. More of the sun's rays reaches the earth in equatorial regions than in the polar regions.

Slope of the land: A surface at right angles to the sun's rays receives more heat. However, if the same rays strike the earth surface at right angles it will cover more area. Thus the same quantity of heat is spread over greater area, and the energy received per unit area is proportionally reduced.

Vegetation: Bare soils warm up more quickly and cool off more rapidly than those covered with vegetation. Vegetative cover intercepts sun's rays and soil beneath does not become warm. In winter, vegetation acts as insulator and reduces loss of heat from the soil. Plant cover protects the soil from getting cool as it retards the loss of heat. Hence, soils carrying a dense plant cover are cooler in summer and warmer in winter than unprotected soils.

Soil colour: In general, dark coloured soils absorb more heat because of their greater water holding capacity. Light coloured soils reflect greater part of the heat back into the atmosphere. Hence, black or brown soils are warmer than gray soils. All black soils do not absorb more heat. Those rich in humus are cooler as the heat capacity of humus is less than that of mineral matter.

Soil depth and time: Soil temperature changes with depth and time of the day. Heat flow is slower in soil than in the atmosphere. The deeper the soil layer, the longer it takes a temperature change to reach it and less will be the temperature fluctuations from day to day or week to week. On cool nights, the deep soil layers do not cool as fast as surface layers. This is because of the insulating effect of the overlying soil. The standard soil temperature is measured at a depth of 50 cm.

Nature of soil: (a) Soil texture: Sandy soils, in general warm up quicker than clayey soils. As clay soils contain a large amount of water, they warm up slowly.

Table 12.1. Specific heat of soil constituents

Soil material	Specific heat (cal/g/°C)
Coarse quartz sand	0.191
Quartz powder	0.189
Feldspar	0.194–0.205
Mica	0.206–0.208
Apatite	0.183
Fe ₂ O ₃	0.165
Humus	0.443

(b) Soil structure: Soils having better structural conditions (air space in soil) warm up rapidly.

Specific heat of soils: Specific heat, is the calories of heat required to raise the temperature of 1 g of the substance through 1°C. The specific heat of water is 1.0, which is much higher than the mineral components of soil (Sp. heat of dry soil is 0.2 cal/g). The specific heat of important soil constituents is presented in Table 12.1. The heat capacity of a given material is equal to its specific heat times its mass.

Thus 1 calorie of heat will raise the temperature of soil much more than that of water. For example, with 20% moisture in a soil the specific heat of a soil is raised to 0.33 and with 30% it goes up to 0.38. Thus a dry soil is easily heated as compared to a moist soil. Consequently, a soil with greater moisture in it needs more heat to raise its temperature to the level of a dry soil.

Heat of vaporization: Low temperature of a wet soil is because of (i) latent heat of vaporization of water, which are 540 kilocalories/kg. of soil. In other words, the temperature of a moist soil can only be lowered after loss of this heat. This helps in maintaining lower temperature of a wet soil (ii) high specific heat of water does not permit rise in soil temperature.

Conduction of heat in soil: This refers to the amount of heat that penetrates the soil profile. In other words, it includes the amount of heat, which is not reflected back from the surface of the soil. The rate of heat conduction is controlled by the amount of moisture in the soil. In general, heat passes 150 times faster from soil to water than from soil to air. This heat is conducted very easily through a wet soil.

Problem: If a soil contain 25% moisture, calculate the specific heat of the soil

Given: Sp. heats of water 1 cal/g, Sp. heats of soil solid 0.2 cal/g.

Solution

There are 25 g of water in 100 g of soil (given)

The number of calories required to raise the temperature of 25 g of water by 1°C
 $25 \times 1 \text{ cal/g} = 25 \text{ Calories.}$

The number of calories required to raise the temperature of 100 g of soil solids by 1°C is $100 \text{ g} \times 0.2 \text{ cal/g} = 20 \text{ Calories}$

Total calories required to raise the temperature of 125 g of moist soil by

$$1^{\circ}\text{C} = 25 + 20 = 45 \text{ Calories}$$

Since Sp. heat is the number of calories required in raising the temperature of 1g of wet soil by 1°C .

$$\text{Sp. heat of the soil} = 45/125 = 0.36 \text{ cal/g.}$$

THERMAL CAPACITY

Thermal capacity or heat capacity of a given material is equal to the specific heat of its components multiplied by their masses. The major constituents of soil are mineral matter, organic matter, water and air and their specific heat values are 0.181, 0.462, 1.00 and 29 respectively.

$$\text{Specific heat of soil} = M_1S_1 + M_2S_2 + M_3S_3 + M_4S_4$$

As masses of air and organic matter are very low, they may be neglected. Thus, heat capacity of a mineral soil,

= Heat capacity of solid phase + heat capacity of water

= 0.46 (Volume fractions of mineral matter) $\times$ 0.60 (Volume fractions of organic matter) + heat capacity of water

It is expressed as cal/g/ $^{\circ}\text{C}$.

THERMAL CONDUCTIVITY

Thermal conductivity or *heat conductivity* is defined as the quantity of heat that flows through a unit area of unit thickness in unit time under a unit temperature gradient.

This can be explained by visualizing the flow of heat through, rectangular section (Fig. 12.2). Let the temperature on each side of this rectangular section be equal to T_1 and T_2 , the thickness of section be equal to d , and the amount of heat that flows across in a unit time t equal to Q and a cross section $A \text{ cm}^2$.

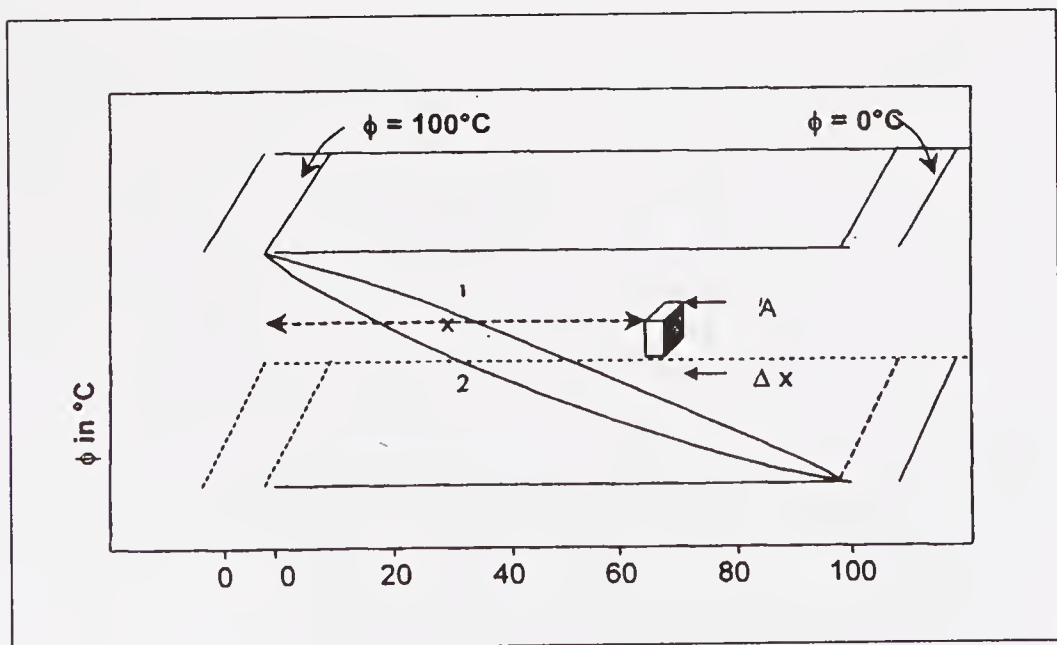


Fig. 12.2. Flow of heat through soils

The rate of flow of heat per unit area will be Q/AT (curve 1). The temperature gradient will be:

$$K = \frac{Q/At}{(T_1 - T_2)/d} \quad \text{or} \quad \frac{Qd}{At (T_1 - T_2)}$$

The thermal conductivity of soils is of the order; Sand > loam > clay. These conductivity differences are due to difference in the porosity and packing of particles. With increase in bulk density, the porosity is reduced which increases contact between solid particles and thermal conductivity is increased. The presence of water films between particles improves thermal contact and increase thermal conductivity.

THERMAL DIFFUSIVITY (K/C)

It is the change in temperature in °C in 1 sec. when the temperature gradient changes by 1°C /1cm³. Thus it measures change in heat when heat flows in a layer from a layer adjacent to it. Considering Figure 12.2, the heat that flows from one side of the rectangular section is not the same, which leaves on its other side. The temperature at each point is changing as indicated in the curve 2.

Let the mean temperature of the section rise by a small amount $d\Theta$ in a small unit time dt . The quantity of heat that is necessary per unit time to raise the temperature will be equal to $Ac/(dQ/dt) \Delta X$ where ΔX is the thickness of distance, C is the heat capacity of the soil (C = the effective specific heat of soil $\times$ apparent density), dQ/dt . the change in heat This indicates that the amount of heat required is equal to the volume of the section $A \Delta X$ times its capacity C times the change in temperature dQ/dt .

Thus, if there is no heat loss, then

$$\begin{array}{ccccc} AK & \frac{d^2\Theta}{dx^2} & \Delta X & AC & \frac{d\Theta}{Dt} \Delta X \\ \\ K & d^2\Theta & = & \Delta\Theta & \\ \hline C & dX^2 & = & \Delta t & \end{array}$$

This is the fundamental equation for calculating the heat conductivity K , from effective heat capacity C , the rate of the temperature gradient $d^2 \Theta/dX^2$, and the change in temperature at a given point with time $d\Theta/dt$. The expression K/C is termed thermal diffusivity and expressed in cm²/sec. The thermal diffusivity of soil may either increase or decrease with increasing moisture content, since k , p and c all increase with it. But in general, starting with a dry soil, it first increases and after reaching a peak, may decrease slightly.

SOIL TEMPERATURE FLUCTUATION

Other things being equal, the temperature of soil in regions of high rainfall is

lower than where it is less. In regions where rainfall is evenly distributed, the diurnal range of soil temperature is lower than in areas where rainfall is concentrated during a few months of the year. The presence of water is responsible for absorbing heat. Thus, amount of solar energy reaching the surface is reduced. There are notable differences in the seasonal, monthly and daily temperatures. Such changes in temperature occur on both surface as well as sub surface layers in a soil profile. Since the sub soils are not subject to direct effects of solar radiation, the sub soil temperatures are less variable than the surface soil temperatures. Also, the subsoil shows little daily or weekly fluctuations as compared to surface soils.

Use of mulches in the form of organic residues acts as buffer for changes in soil temperature. Mulches prevent loss of moisture through radiation and conserves soil moisture. Because of high specific heat of water it regulates soil temperatures. This also facilitates root development in the surface soil as temperature plays a significant role in seed germination and root development. All management practices, which conserve soil moisture, are beneficial in maintaining soil temperature.

Diurnal changes

The diurnal changes in soil temperature depend upon the intensity of solar radiation received at the surface and the loss of heat. Heat moves downward during day when the surface soil is more hot and upward to the surface at night when the lower layers are hotter. Thus, there is a diurnal or alternate rise and fall in soil temperature with the rising and setting of the sun. The magnitude of change varies with different soils.

Seasonal changes

Soil temperature changes with the season. This is associated with differences in moisture content of the soil and seasonal variations in insolation. A record of variations in soil temperature at the surface soil, variations in air temperature, day temperature throughout the season may reveal seasonal changes. A comparison of soil temperatures in different seasons may be made. The magnitude of difference in temperature of the upper and lower layers, varies with the season. In general, the difference is the greatest during hot weather and the least during monsoon.

EFFECT OF SOIL TEMPERATURE ON PLANT GROWTH

Soil temperature is an important plant growth factor and also influences the availability of water and nutrient. Soil temperature changes the soil environment, which in turn affects plant growth. This may be discussed under following parameters.

Seed germination and root growth: Seed germination and root growth of most crops are markedly influenced by changes in soil temperature. For example, maize requires soil temperature of 7–10°C for germination and optimum root growth occurs at about 25°C. At low temperature, root elongation is retarded. Plants vary in their optimum requirement of temperature they need for their best growth. For example, wheat grows best at 24°C. Onion prefers a cool (< 15°C)

climate, while melons thrive best in the hot ($> 38^{\circ}\text{C}$). In general, the physiological activities are accelerated by a rise in temperature. High temperature is conducive to rapid growth of most crop plants. The solubility of food nutrients and their availability are influenced by soil temperature.

Microbial activity: At low temperatures, metabolic activity and enzymatic reactions are slowed down. At high temperature ($>35^{\circ}\text{C}$), nitrification is adversely affected. The optimum temperature for the activity of most of the microorganism is in the range of $25\text{--}35^{\circ}\text{C}$. Microbial activity is lowest in winter when the temperature is low and the highest in spring when there is a rise in temperature. In summer, when the soil temperature rises, there is a decrease in biological activity.

Absorption of water and nutrients: At low temperature, the absorption and translocation of water and nutrient ions are adversely affected. Movement of water in plants is slowed down due to increased viscosity. The rate of nutrient uptake, though almost different for each crop, the relative effects of temperature on the uptake of nutrients are known.

Decomposition of organic matter: The decomposition products of organic matter vary with the rate of decomposition of organic matter. At low temperature the rate of organic matter decomposition is low resulting in formation of toxic organic substances. Beneficial products of organic matter decomposition results when microbial activity is fast at optimum temperature. Soil temperature influences the type and amount of decomposition products, which affect soil aggregation. Soil temperature thus indirectly affects soil structure.

Plant diseases: There are risks of damage to moist seeds by fungi, and bacteria, if the germination is prolonged due to low temperature. Seedlings adapted to grow at lower temperature, however, are resistant to their attack.

Soil Temperature Management

Our ability of controlling soil temperature is limited. Management of soil temperature is important since small changes in soil temperature have pronounced effect on plant growth. Soil temperature can be managed through.

Changes in moisture content of soil: Under dry conditions where temperature is very high, addition of water lowers temperature. Under waterlogged conditions, removal of excess water lowers its specific heat and thus increases the soil temperature.

Use of mulches: Mulches affect the amount of heat received and its dissipation. Various type of mulches include dead vegetation grass and straw and artificial mulches like plastic and polythene films, Mulches (i) reduce soil temperature fluctuations, (ii) mulches including vegetation provide plant nutrients after their decomposition, Vegetation uses radiant energy for the process of photosynthesis and transpiration. Consequently it keeps the soil relatively cool. A black polythene mulch on the soil may increase growth of fruit crops in cooler regions. The growth increase was attributed to an increase in soil temperature during winter. Black mulches also retain moisture and control weed growth.

Application of organic matter: Organic matter provides a dark-colour to soils because of high water content which helps in lowering down the temperature.

Use of ridges in soil: Positioning plants to receive direct sunlight by planting

on ridges (sloping surface receives more radiation from the sun) can modify the problem of high temperatures.

References and Suggested Readings

- Baver, L. D., Gardner (1976). *Soil Physics*. Wiley Eastern Ltd., New Delhi.
 Bear, F. (1964). *Chemistry of the Soil*, 2nd edn. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi.
 Hillel, D. (1982). *An Introduction to Soil Physics*. Academic Press, New York.
 Kohnke, H. (1968). *Soil Physics*. McGraw Hill Book Co., New York, USA.
 Miller, R.W. and Donahue, R.L. (1997). *Soils in our Environment*. Prentice Hall of India, New Delhi.
 Oswal, M.C. (1983). *A Textbook of Soil Physics*. Vikas Publishing House Pvt. Ltd., New Delhi.

QUESTIONS

Q.1. Fill in the blanks

- i) The specific heat of water is _____, which is much higher than the mineral components of soil.
- ii) The heat capacity of a given material is equal to its specific heat times _____.
- iii) The presence of water films between particles improves thermal contact and increases _____.
- iv) At temperature above 35°C, _____ process is adversely affected.
- v) Total solar energy falling on the earth is equivalent to _____ per square centimeter per year.
- vi) Thermal capacity is expressed as _____.
- vii) Wheat grows best at _____ °C.
- viii) The latent heat of vaporization of water is _____ Kcal /kg. of soil.
- ix) The specific heat of humus is _____ cal/gm/°C.
- x) Under dry conditions where temperature is very high, addition of water _____ temperature.

Answers

- (i) 1.0 (ii) its mass (iii) thermal conductivity (iv) nitrification (v) 75,000 calories (vi) cal/g/°C (vii) 24°C (viii) 540 (ix) 0.443 (x) lowers

Q. 2. Choose the correct answer

- i) There is an increase / decrease in soil temperature as one proceeds from the arctic to the equator
- ii) Heat capacity of humus is less / more than that of mineral matter.
- iii) Heat flow is slower / faster in soil than in the atmosphere
- iv) On cool nights, the deep soil layers do not cool / cool as fast as surface layers.
- v) The thermal conductivity of sand is more / less than clay.
- vi) In general, lighter / dark colored soils reflect greater part of the heat back

into the atmosphere.

- vii) Under dry conditions where temperature is very high, addition of water lower / increases temperature.
- viii) The subsoil / surface soil shows little daily or weekly fluctuations as compared to surface soils.

Answers

- (i) increase (ii) less (iii) slower (iv) do not cool (v) more (vi) lighter (vii) lower (viii) subsoil

Q. 3. Define the following

- (i) Specific heat (ii) Thermal capacity (iii) Thermal conductivity (iv) Thermal diffusivity

Q. 4. Differentiate between

- (i) Seasonal and Diurnal changes in soil temperature (ii) Microbial activity in winter and summer as compared to their activity during spring season

Q. 5. Write short notes on

- (i) Management of soil temperature (ii) Role of mulches in maintaining soil temperature

Q. 6. Comment on the following statements

- i) $R_N = R_L$ (Net radiation = longwave far infrared radiation)
- ii) More heat reaches the earth during the afternoons when the sun is low in horizon
- iii) Bare soils warm up more quickly and cool off more rapidly than those covered with vegetation
- iv) Clay soils warm up quickly as compared to sandy soils
- v) A dry soil is easily heated as compared to a wet soil
- vi) The rate of heat conduction is controlled by the amount of moisture in the soil
- vii) Bulk density and water influences thermal conductivity of a soil
- viii) More heat reaches the earth during the afternoons when the sun is low in horizon.
- ix) Bare soils warm up more quickly and cool off more rapidly than those covered with vegetation.
- x]. A dry soil is easily heated as compared to a wet soil.
- xi) The temperature of a wet soil is low.
- xii) Heat is conducted easily through a wet soil.
- xiii) Management practices that conserve soil moisture is beneficial in maintaining soil temperature.
- xiv) Plants at low temperature adversely affect the absorption and translocation of water and nutrient ions.

Q. 7. Answer the following in brief

- i) Enlist factors affecting quantity of energy reaching the soil through solar radiation.
- ii) How does change in soil temperature influences a) decomposition products

- of organic matter (b) incidence of plant diseases
- iii) What is the role of vegetation in maintaining soil temperature

Q. 8. Answer the following in detail

- i) Give a detailed account of 'Effect of soil temperature on plant growth'.
- ii) Explain factors influencing soil temperature

Q. 9. Give diagrammatic view of the following

- (i) Effect of slope, direction and the sun's position on the heat supplied to soil.



SECTION C

**Physical
Chemistry
of Soil**

13

Soil Colloids

THE physical chemistry of soils is essentially a study of the most reactive fractions of soils, or the so-called colloidal phase. The colloidal particles play important role in determining the physical and physico-chemical properties and reactions that occur in soils. A colloid is a very tiny particle, usually smaller than 1 micrometer in diameter. Nutrients are adsorbed on soil colloidal particles. Hence the constituents of soil which are in the colloidal state are the seats of reactions in soil. Clays are important colloidal materials. The term 'clay fraction' should not be confused with the term 'clay minerals'. The clay fraction may contain clay-sized particles, which are not clay minerals. Similarly clay minerals may occur in particles which are too large to be included in the clay fraction.

The colloidal state refers to a two-phase system in which one phase in a very finely divided state is dispersed through a second one. The most active portions of soil are those in the colloidal state. Soil colloids may be classified as follows:

Inorganic colloids: a) The silicate clays b) The iron and aluminium oxide clays (prominent in well weathered soils of tropics and semitropical regions)

Organic colloids: Humus

PROPERTIES OF COLLOIDS

Since colloidal particles occur in a colloidal state, soil colloids form dispersed phase, dispersed in a dispersion medium (soil solution). Colloid exhibit distinct properties like adsorption, electronegative charge, tyndall effect, brownian movement, cataphoresis, electro-osmosis, coagulation, and other related properties.

Adsorption: The surface area exposed by colloidal particles is very large because of their small size. The internal interface between plate like crystal and external surface area further increase the surface area of clays. The surface area or specific surface, is the surface area per unit volume. If the surface area of a sphere is πd^2 and the volume of the same sphere with diameter d equals $1/6 \pi d^3$ then specific surface $S = \pi d^2 / (1/6 \pi d^3)$
$$= 6/d$$

If we assume that clay particles are spheres with $d=0.002$ mm, then the specific surface of clay is $S= 6/0.002 = 3000 \text{ mm}^2/\text{mm}^3$

The specific surface of the fine clay fraction (<0.0002 mm) is:

$$S=6/0.0002 = 30,000 \text{ mm}^2 / \text{mm}^3$$

This value is however hypothetical as clay particles are plate like in shape.

This may also be explained if we take a cube of 1 cm. edge, the surface area exposed by this cube is 6 cm^2 . When this cube is subdivided into 8 cubes of edges 0.5 cm, the surface area exposed is 12 cm^2 . If this division is made into 10^3 cubes

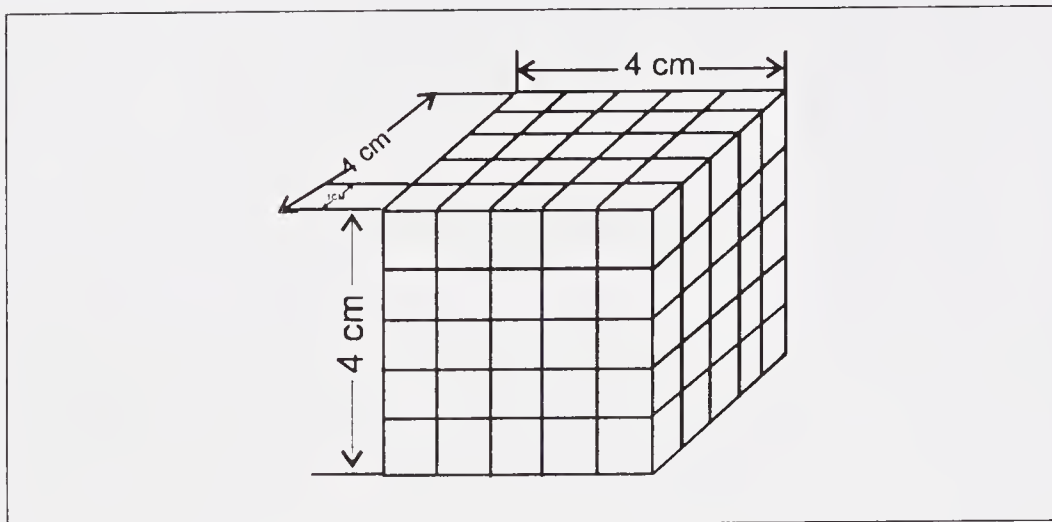


Fig. 13.1. Surface area effect on a cube

such that each side is equal to 0.1 cm, the surface area is 60 cm². The external surface area of 1 g of colloidal clay is 1000 times that of 1 g of coarse sand. Thus due to the large surface exposed by colloidal particles, they have tremendous adsorptive properties. A cube of 4 cm each side and 1 cm each side has a surface area of 96 cm² and 384 cm² respectively (Fig. 13.1).

Total area of 4 cm² cube = area of each side × number of sides × number of cubes
 $= 4 \times 4 \times 6 \times 1 = 96 \text{ cm}^2$

Total area of 1 cm² cube $= 1 \times 1 \times 6 \times 64 = 384 \text{ cm}^2$

$$\text{Number of cubes of 1 cm}^3 = \frac{\text{Volume of large cube}}{\text{Volume of small cube}} = \frac{4 \times 4 \times 4 \text{ cm}^3}{1 \times 1 \times 1 \text{ cm}^3} = 64$$

Electronegative charge: The clay particles are usually negatively charged.

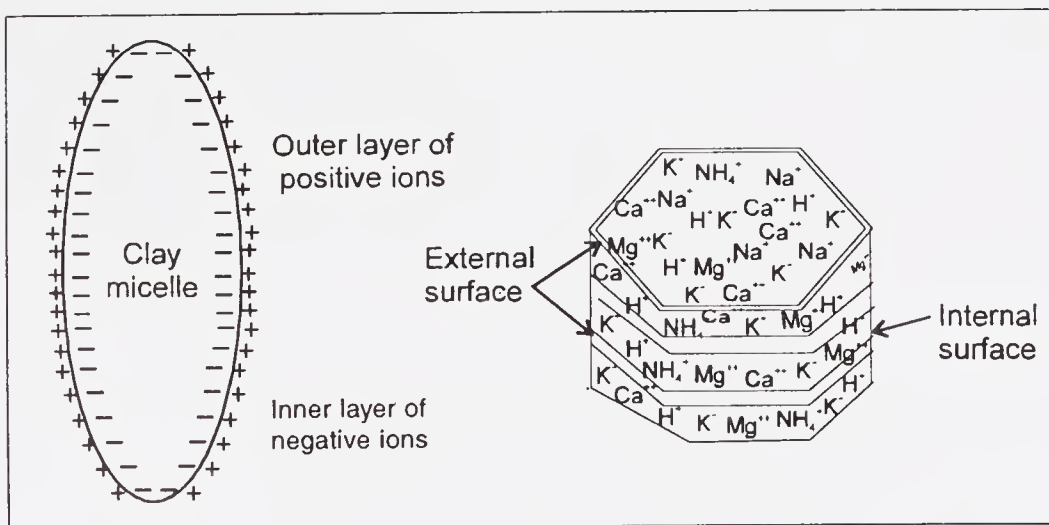


Fig. 13.2. (A) The negative charge of the clay micelle forms the inner layer and the positive charge of the cations the outer layer

Fig. 13.2. (B) Clay micelle showing adsorbed cations on internal and external surface

Thus, positively charged cations are attracted and held on its surface. This forms ionic double layer, the inner layer consists of negatively charged ions. The outer layer is made up of loosely held cations by a large number of water molecules. As the cations are loosely held, they are exchangeable. (Fig. 13.2 (A) and (B)).

Tyndall effect: If a strong beam of light is passed through a colloidal suspension, the particles become visible and they appear bigger than they are. This is due to diffusion of light by colloidal particles. This phenomenon was studied by Tyndall and is therefore called Tyndall effect.

Brownian movement: If seen under a microscope, colloidal particles are in a constant zigzag motion. This is because colloidal particles are negatively charged and thus repel each other. Sir Robert Brown first discovered this phenomenon in 1827 (Fig. 13.2).

Cataphoresis: The migration of colloidal particles under the influence of an electric field is called cataphoresis. This is because colloidal particles are electrically charged and hence move towards oppositely charged electrodes when placed under an electric field. Thus cataphoresis helps in determining the charge on the colloidal particles.

Electro-osmosis: The movement of dispersion medium towards colloids made stationary by fixing a porous diaphragm under the influence of an electric field is called Electro-osmosis. This is due to the presence of charges on the colloids.

Dialysis or coagulation: Adding a small amount of oppositely charged ions can coagulate colloidal particles. For example, clay is coagulated by use of alum (Al^{3+} ions). Thus colloidal particles can be separated from crystalloid by dialysis. Crystalloid present as impurities passes through leaving a pure suspension of colloids.

CHARACTERISTICS OF SILICATE CLAYS

Apart from the properties of colloids discussed above, clays in particular exhibit important characteristics as related to their shape and structure.

Shape: Clay particles are made up of layers of plates and are crystalline. The shape determines the amount of effective surface area per unit mass. These particles easily slide over each other and possess high cohesion.

Hydration: There is a large and indefinite amount of water adsorbed by the surfaces of clay particles. The cations adjacent to clay minerals are also hydrated.

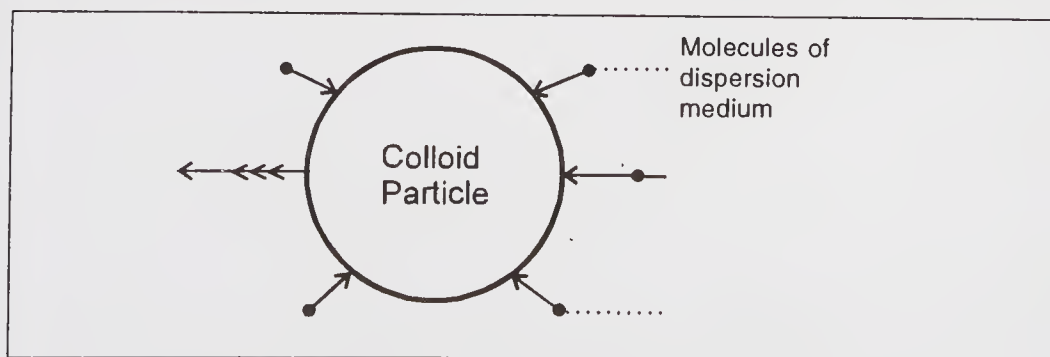


Fig. 13.3. Brownian movement in colloidal particles

Water is held at the internal and external surfaces and between the silica and alumina plates of the clay crystals. The total water held is called water of hydration. Water of hydration may be planer where water molecules are held on crystal surfaces by electrical fields and is large in quantity. The unsatisfied valence bonds at the edges of the clay crystal tightly hold water adsorbed by clay.

Heat of wetting: If a dry soil or clay is placed in water alcohol or other organic solvent heat is evolved during the adsorption of their molecules. This evolution of heat is known as heat of wetting. The heat of wetting decreases as the moisture content of the clay increases. Heat of wetting is measured in calories per g of dried clay, (at 110°C). It is due to (1) a change in the state of water directly adjacent to the adsorbing surface and (2) the possible hydration of adsorbed ions. Ion hydration is the major cause of heat of wetting. This has been used as a method for estimating colloidal content of soil.

PHYSICAL PROPERTIES OF SOIL COLLOIDS

Since shape, size, surface area, adsorption and hydration are all prominent characteristics of clays, it gives rise to certain other properties, which are characteristically surface phenomena and depends upon the amount and nature of interfaces presented by them. They are described as follows:

Plasticity: This means the capacity to be molded. This is due to plate like nature and binding influence of adsorbed water in clay particles. Thus the particles easily slide over each other with films of water between them. Soils containing more than 15% clay exhibit plasticity. Plasticity is evident by two plastic limits.

Soils with wide range between these two plastic limits have poor workability. Plasticity is affected by type of clay and cation. Thus, soils dominated by montmorillonite with its wide ranges between upper and lower plastic limits are difficult to handle as compared to those dominated by kaolinite or illite clay minerals. Soils dominated by sodium have wider variation between their lower and upper plastic limits than those dominated by calcium or hydrogen as the dominant cation. Thus sodium clays are more plastic than calcium or hydrogen clays. High plasticity is not a desirable quality in soils. Heavy soils, if ploughed when wet, will be readily puddled which is detrimental to proper aeration and drainage.

Cohesion: As the water content of wet clay is reduced there is an increase in the attraction of colloidal particles for each other. This is because of attraction of

Table. 13.1. Plastic limits of important clays

Type of clay	calcium saturated		sodium saturated	
	Lower limit	Upper limit	Lower limit	Upper limit
Montmorillonite	63	177	97	700
Illite	40	90	34	61
Kaolinite	36	73	26	52

* From Snow (1949)

clay particles for remaining water molecules held between them. Hydrogen bonding between clay surfaces and water (adhesion) and among water molecules (cohesion), are involved. Montmorillonite and illite exhibit more cohesion than kaolinite. Humus reduces the attraction of clay particles for each other.

Swelling and shrinkage: Swelling in clay is due to

- Water between crystal layers.
- Water attracted to ions adsorbed by the clays.
- Water entrapped into small pores of soils.

This property is exhibited distinctly in montmorillonite minerals because of their expanding lattice and small size of particles. It occurs least in kaolinite because of their non-expanding lattice. Therefore, soils dominated by montmorillonite allow rain water to penetrate because of their deep wide cracks after dry spells but later it forms impervious layer because of shrinkage which takes place on drying.

Flocculation and De-flocculation

Colloidal particles have the ability to aggregate into small floccules (phenomena of flocculation and de-flocculation (see chapter 9). It leads to formation of stable aggregates depending on the type of cation adsorbed on the colloidal clay. De-flocculation on the contrary, is the opposite of flocculation, causes dispersion of particles and destabilizes soil aggregates.

CLAY MINERALS THEIR TYPE AND STRUCTURE

Basically, it comprises of two units

Silica tetrahedron: It consists of one silicon ion surrounded by four oxygen anions. Tetrahedral sheet: A series of tetrahedrons tied together horizontally by shared oxygen anions forms a tetrahedral sheet (Fig. 13.4).

Alumina octahedron: It consists of an aluminium ion surrounded by six oxygen or hydrogen forming an eight-sided block. Octahedral sheet: Numerous

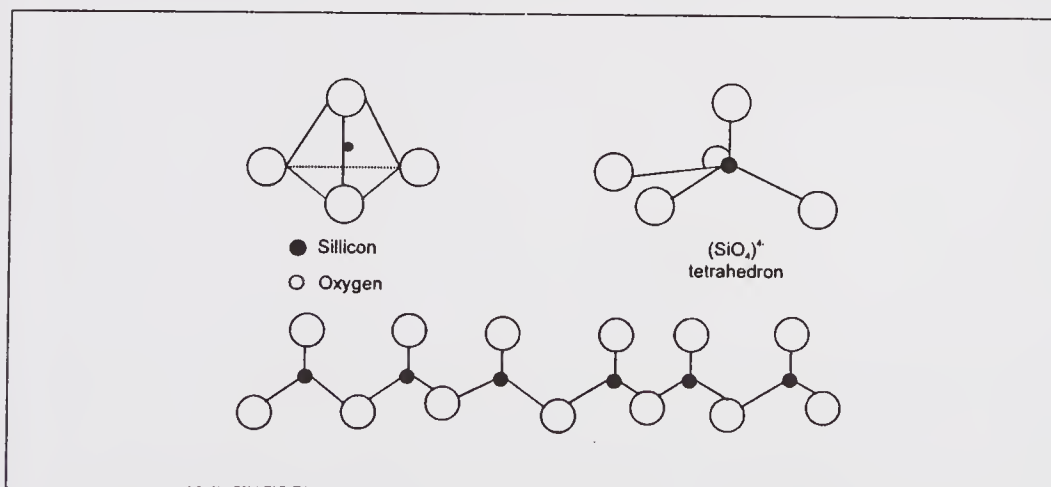


Fig. 13.4. A single silica tetrahedron. The arrangement of silica tetrahedra by shared oxygen atoms

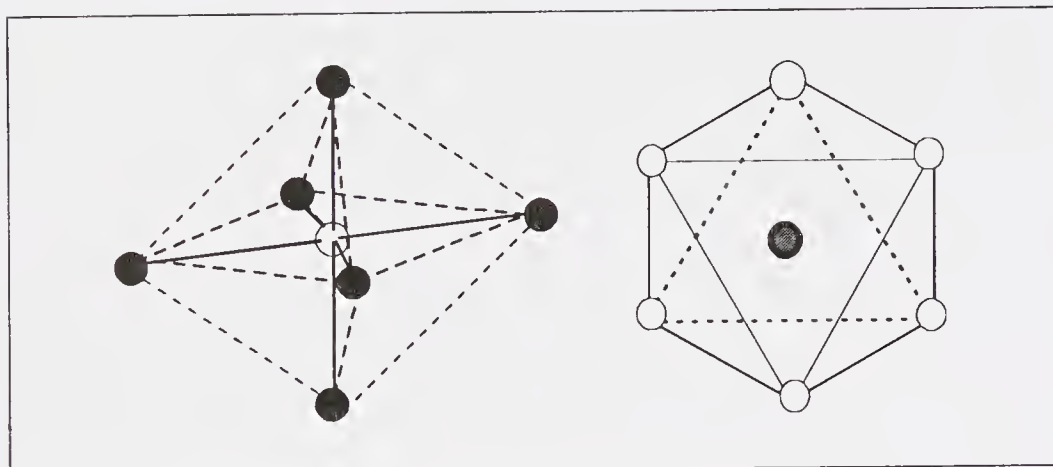


Fig. 13.5. A single octahedron. Octahedrally coordinated aluminium.

octahedrons linked together horizontally forms a octahedral sheet (Fig. 13.5).

Di-octahedral sheet: It is dominated by aluminium (Al^{3+})

Tri-octahedral sheet: It is dominated by magnesium (Mg^{2+}).

Classification of Clay Minerals

Crystalline

Two-layer type (Sheet structure composed of units of one layer of silica tetrahedron and one layer of alumina octahedron)

a) Equidimensional - Kaolinite group; Kaolinite, nacrite etc.

b) Elongate- Halloysite group

Three-layer type: (Sheet structure composed of two layers of silica tetrahedrons and one central octahedral or trioctahedral layer)

Expanding lattice

a) Equidimensional – Montmorillonite group; Montmorillonite, Sauconite etc.; Vermiculite

b) Elongate - Montmorillonite group; Nontronite, Saponite, Hectorite

Non Expanding Lattice – Illite group

Regular mixed-layer type: (ordered stacking of alternate layers of different types)

Interstratified and Mixed Layer Minerals

Non crystalline or Amorphous : Allophane group

Silicate clays are classified on the basis of number and arrangement of the tetrahedral and octahedral layers as follows:

Type clay minerals (Two-layer type): It consists of one silica tetrahedral layer and one alumina octahedral layer (Fig 13.6, 13.7). Kaolinite is prominent in this group. One silica tetrahedral layer is joined with one aluminium octahedral layer. The top oxygen of the silica tetrahedral layer occupies the position of the oxygen of the octahedral layer and is common to the tetrahedral and octahedral layer (Fig 13.8). A weak negative charge develops on the surface of the basal

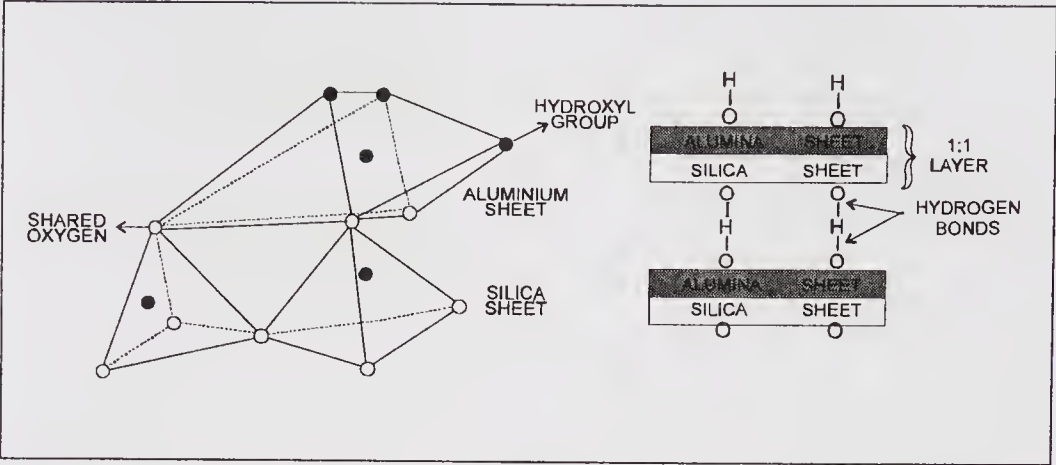


Fig. 13.6. Silica alumina sheet

Fig. 13.7. Hydrogen bonding between silica and alumina sheet

oxygen of the silica tetrahedral layer and a weak positive charge develops on the surface of the hydrogen of the hydroxyl of the aluminium octahedral layer. The positive charge on the hydroxyl surface attracts the negative charge on the oxygen surface. Hence the kaolinite units are tightly bound by hydrogen bonds. Cations and water do not enter between the structural layers of the particle. The effective surface of kaolinite is restricted to its outer faces and external surface area.

Halloysite: Halloysite is the second most common member of the group and has similar composition to kaolinite but contains sheet of water between kaolinite layers. The crystals have a tubular appearance. Water is firmly attached by

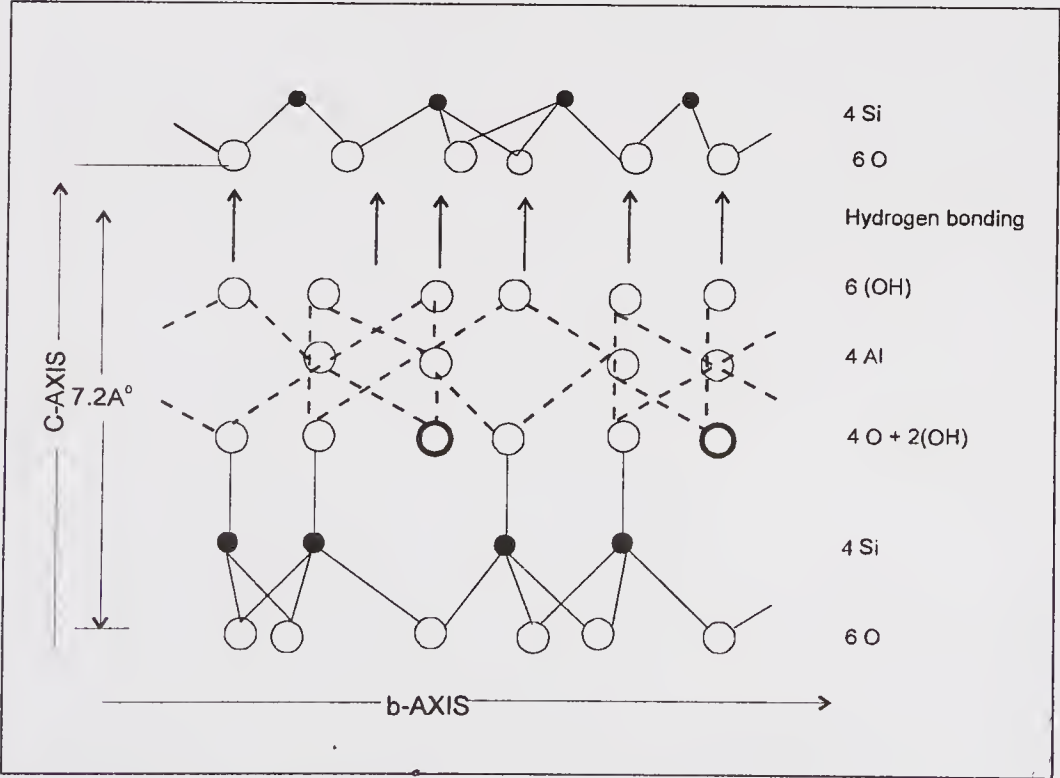


Fig. 13.8. The structure of kaolinite

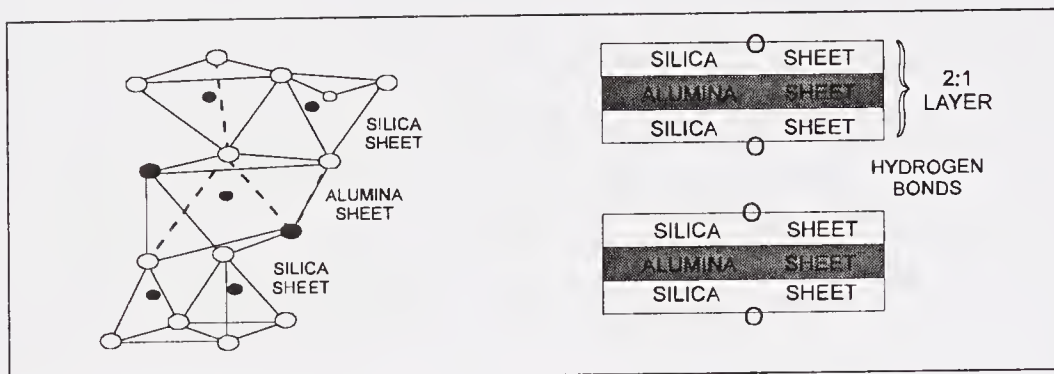


Fig. 13.9 (A) : Silica alumina sheets in 2:1 clay minerals.

Fig. 13.9 (B) : Interlayer space between two sheet of a 2:1 clay mineral.

hydrogen bonding resulting in a rigid structure. However, dehydration can take place very easily causing collapse of the structure forming a mineral similar to kaolinite.

Nacrite and dickite: These minerals differ from kaolinite in the orientation of OH groups involved in the inter layer bonding.

Type Clay Minerals (Three layer type)

It consists of two silica tetrahedral layers and one alumina octahedral layer between them (Fig 13.9-A and 13.9-B).

These are further divided into (a) 2:1 type expanding b) 2:1 type non-expanding.

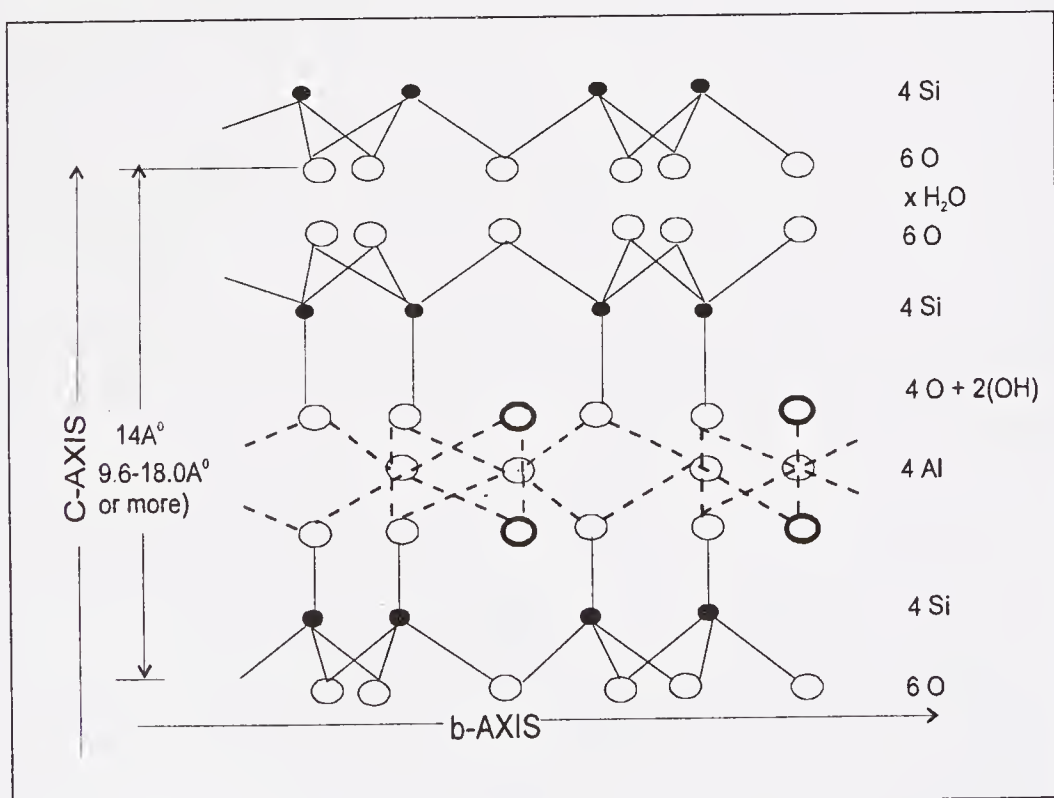


Fig. 13.10. The structure of montmorillonite

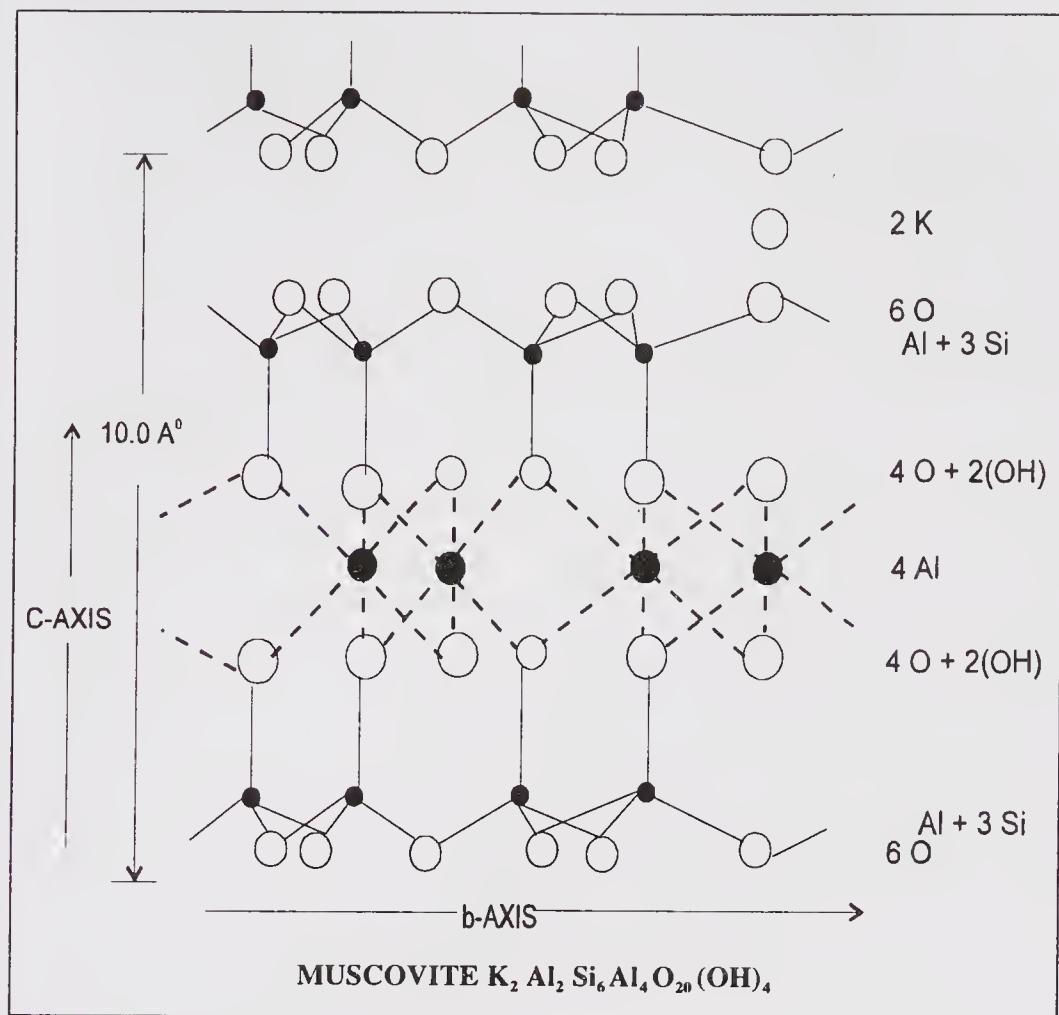


Fig. 13.11. The structure of muscovite

2:1 Type Expanding Lattice

It includes the smectite group, which consists of montmorillonite, beidellite, nontronite and saponite.

One central layer of alumina octahedron is attached with two layers of silica tetrahedron, one at the top and the other at the bottom as shown in Fig. 13.11. There is a considerable isomorphous substitution mainly in the octahedral layer. Isomorphous substitution of Mg^{2+} for Al^{3+} in the octahedral sheet and of Al^{3+} for Si^{4+} in the tetrahedral sheet results in a net negative charge. A weak negative charge also develops on the oxygen surface of such clay minerals, which repel each other. This results in an increase in the interlayer space. Such crystals may easily expand where cations and water molecules are attracted.

Negative charges in a few clay minerals are developed as follows:

Montmorillonite: There is substitution of Mg^{2+} for Al^{3+} in the octahedral sheet.

Beidellite: There is isomorphous substitution of Al^{3+} for Si^{4+} in the tetrahedral sheet.

Nontronite: Trivalent iron (Fe^{3+}) substitutes for Al^{3+} in the octahedral sheet.

Saponite: There is substitution of Al^{3+} for Si^{4+} in the tetrahedral sheet and of Mg^{2+} for Al^{3+} in the octahedral sheet.

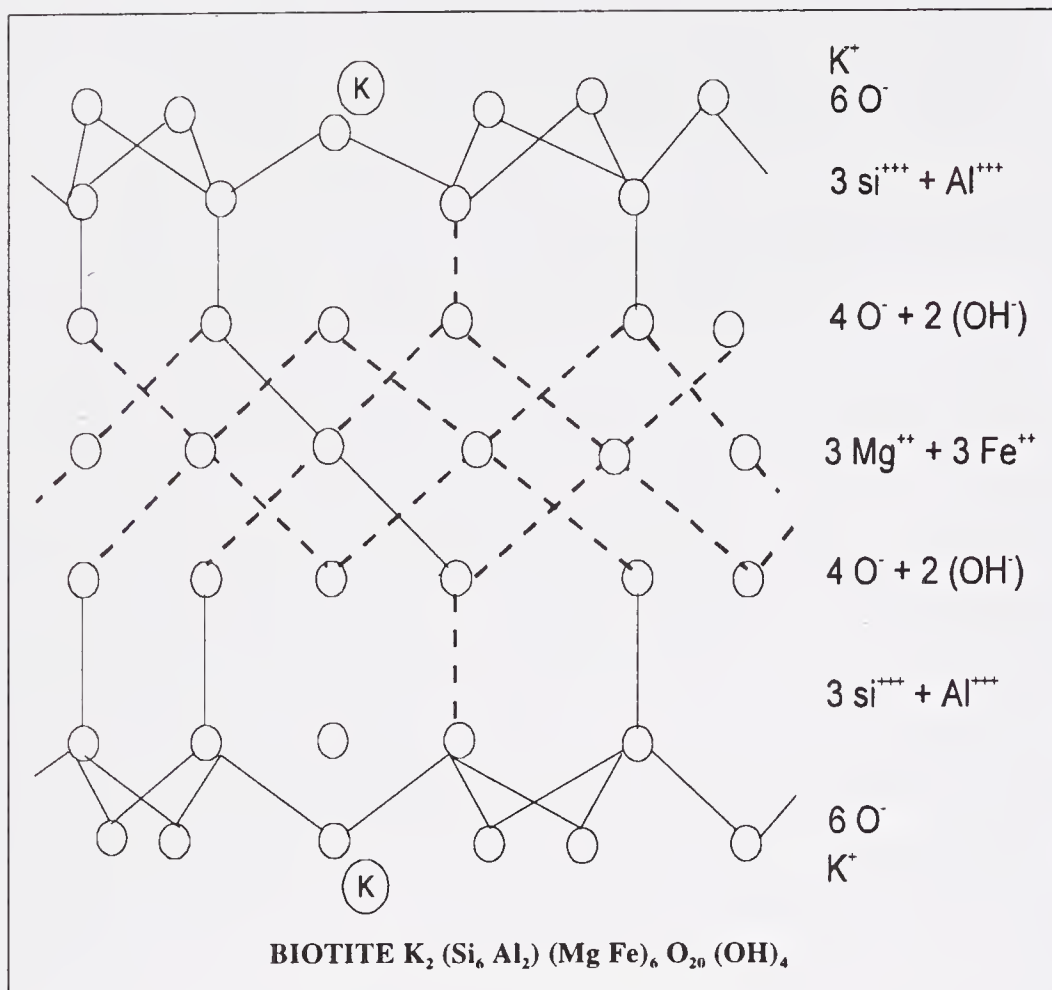


Fig. 13.12. The structure of biotite

Vermiculite: Dioctahedral vermiculite: When of the possible positions are filled by aluminum. This is called Gibbsite structure, $Al_2(OH)_6$ or $[Al(OH)_3]_2$.

Trioctahedral vermiculite: When all the octahedral positions are filled by magnesium. This is also called Brucite structure – $Mg_3(OH)_6$ or $[Mg(OH)_2]_3$.

In the tetrahedral sheets of vermiculites, there is considerable substitution of Al^{3+} for Si^{4+} . This accounts for very high negative charge associated with these minerals. This is the reason for high cation exchange capacity of vermiculites. However, water molecules and magnesium ions are strongly adsorbed in the interlayer space of vermiculites which acts as bridges. The degree of swelling is therefore considerably less for vermiculites than for smectites. Thus vermiculites is known as limited expansion mineral.

2:1 Type Non-Expanding Lattice

Muscovite and biotite are two main members of this group (Fig. 13.12 and 13.13).

One octahedral layer occurs between two tetrahedral layers of silica one at the top and the other at the bottom. The octahedral layer is joined with the tetrahedral layer when the top oxygen of the tetrahedral layer occupies the position of the hydroxyl of the octahedral layer. About 15-20% of the silicon ions in the

Table 13.2. Comparision of properties of important clay minerals

	Kaolinite	Montmorillonite	Illite
Formula	$\text{Si}_4\text{Al}_4\text{O}_{10}(\text{OH})_8$	$\text{Si}_8\text{Al}_4\text{O}_{20}(\text{OH})_4.\text{xH}_2\text{O}$	$\text{K}_2(\text{Si}_6\text{Al}_2)(\text{Al}_4)\text{O}_{20}(\text{OH})_4$
Crystal lattice	1:1, fixed	2:1, expanding	2:1, non expanding
Size(in microns)	0.5 to 2	0.01 to 0.1	0.1 to 1.0
Substitution	No substitution	Substitution in alumina sheet by Mg or Fe	Substitution in silica layer by aluminium
Main type of substitutions	Exposed crystal edges	Isomorphous substitutions	Isomorphous substitutions (by K+)
Heat of wetting (cal/gm)	5 to 6	12 to 18	8 to 10
C.E.C. (cmol/kg)	3 to 15	80 to 100	15 to 40
Anion exchange capacity	High	Low	Medium
Total surface area (m2 g)	37 to 45	600 to 750	120 to 170
External m2 g)	30 to 35	80 to 150	50 to 70
Internal surface area (m2 g)	7 to 10	500 to 600	70 to 100
Physical properties:			
a) Cohesion and plasticity	Negligible	Highly plastic and cohesive	Medium in plasticity and cohesiveness
b) Porosity and Permeability	Porous, Permeable	Low in porosity and permeability	Medium in porosity and permeability
c) Swelling and shrinkage	Low	High	Medium

tetrahedral sheet is replaced by Al^{3+} ions. This results in a high negative charge in the tetrahedral sheet. This negative charge is satisfied by K^+ ion, which is a binding agent and occurs between two units of illites and bind them tightly. Illite is thus a non-expanding clay mineral.

The negative charges in muscovite and biotite are developed as follows:

Muscovite: When two-third of the octahedral positions are occupied by Al^{3+} ions and one-third are empty. It is also called dioctahedral illite.

Biotite: When all the positions are filled by Mg^{++} or Fe^{++} ions. It is also called tri-octahedral illite.

2:1:1 Type Minerals (Regular Mixed Layer Type)

It consists of two silica tetrahedral layers, one alumina octahedral and one magnesium dominated octahedral layer. Soil chlorites belong to this group of clay minerals. Chlorites are iron-magnesium silicates with some aluminium. Thus, chlorites consist of a layer of vermiculite, i.e. two silica tetrahedral sheets where some of the silica has been replaced by aluminum and a Mg-Fe dominated octahedral sheet (aluminium replaced by Mg and Fe) and one unit of magnesium octahedral layer called brucite layer as shown in Fig. 41. Thus the crystal unit

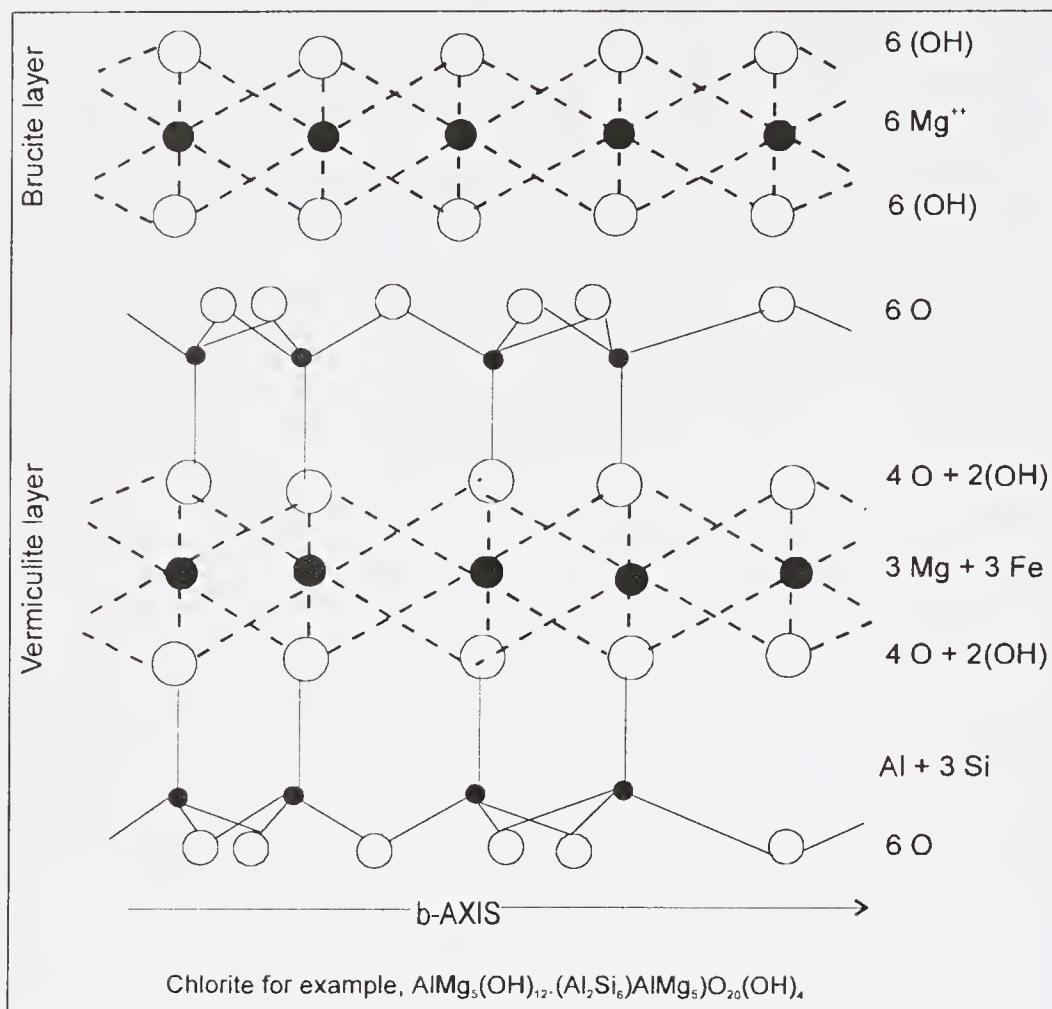


Fig. 13.14. Structure of Chlorite

contains two silica tetrahedral sheets and two magnesium dominated trioctahedral sheets, giving rise to 2:1:1 or 2:2 type of structure.

Interstratified and Mixed Layer Minerals

Clay minerals scarcely occur in pure form in soils, even a single particle is composed of interstratified layers of two or more different clay minerals. Interstratified clays cannot be separated by physical means, as can an ordinary mixture of clays. Minerals having properties and composition intermediate between two well-defined minerals are known as interstratified or mixed minerals. For example, mixtures such as 'kaolinite-vermiculite', 'kaolinite-montmorillonite' and 'illite-smectite' occur frequently. The reasons for occurrence of mixed layers could be formation of 2:1 minerals in the early stages of soil formation (or inherited from the parent material) and then incorporation of kaolinite and iron oxides preventing their further alteration.

Thus, mixed layer minerals are formed as weathering proceeds in soil. A sequence of changes in silicate clay minerals during continuous weathering may be explained as follows:

- Micas, with rigid structures and potassium held tightly between their crystal

units loose some of their potassium and are converted into fine-grained micas, which are less rigid.

- Fine-grained micas being less rigid attract exchangeable cations in their interlayer space and potassium is further leached. Water and magnesium ions bind the layer together and fine grained 'mica- vermiculate' interstratified minerals are formed.
- Further loss of potassium permit entry of more water and exchangeable ions, forming "vermiculate-smectite" mixed minerals.
- More weathering produces smectites, 2:1 type expanded group of minerals
- Smectite on weathering looses exchangeable ions like Mg^{++} and Fe^{++} and other metallic cations. Thus acidic conditions develop and consequently recrystallization leads to formation of kaolinite.
- Further, weathering due to hot and humid conditions in tropics produce oxides of iron and aluminum.

Allophanes

Stromeyer and Hausmann first introduced, the name allophane in 1861 for hydrous aluminosilicates occurring in nature. The allophane clay minerals are amorphous. Allophanes are random arrangement of silica tetrahedra and metallic ions in octahedral co-ordination. They are having a composition $Al_2O_3 \cdot 2SiO_2 \cdot H_2O$ and are formed in soils developed from volcanoes. Their salient features are:

- They have a high cation adsorbing capacity and a low anion adsorbing capacity.
- Amorphous materials in clays and soils show wide variations in their composition. They have varying amounts of other soil constituents and contain Fe_2O_3 and P_2O_5 in their composition. Sometimes they are strongly associated with humus giving dark colored soils.
- Allophanes impart porous structure to soils. Thus leaching is frequent and such soils are infertile.
- Allophanes have a high surface area and the activity of aluminium and iron is very high. Thus such soils have phosphate deficiency due to formation of aluminium and iron phosphates.

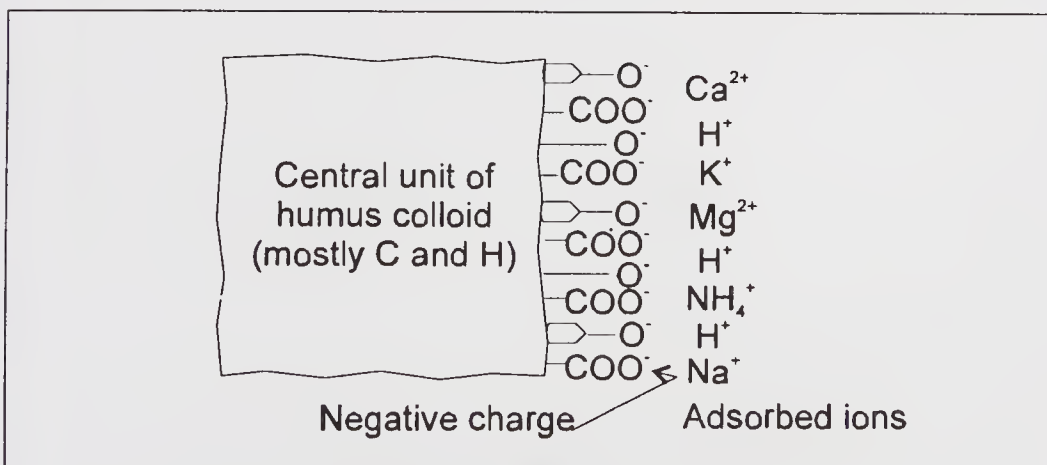


Fig. 13.15. A humus micelle

Genesis of Clay Minerals

The clay minerals are all hydrous silicates or aluminosilicates. They are generally formed by transformation or weathering of primary minerals. The processes involved may be:

- Detrital inheritance
- Physical or chemical alteration of primary minerals
- Decomposition of primary minerals followed by subsequent recrystallization of some of their products

Detrital inheritance: The clay minerals in hot dry or cold dry climates, where chemical weathering is at minimum, are largely inherited from the parent materials. Detrital inheritance may be seen in following examples:

- Sedimentary rocks and unconsolidated deposits are usually inherited
- There is a close association between kind of clay present in parent material and kind of clay in the soil. Micas, which are predominant in the sand and silt fraction represent dominance of illitic minerals on alluvium derived from such deposits

Alteration: Alteration refers to only a slight physical or chemical change. There is no change in the basic structure of the mineral. Alteration may be illustrated in the following examples:

- Alteration of muscovite mica, a rigid structure with no exchangeable K to fine grained mica. As weathering (of muscovite mica) occurs, part of potassium is lost and silicon is added from the weathering solution. The mineral is physically broken and reduced to size of colloidal particles. The fine mica (illite) so formed is less rigid and acquires an electronegative charge. Thus, a part of K is exchangeable in illite.
- The transition from biotite to vermiculite (It involves exclusion of K from biotite).

Recrystallization: Recrystallization occurs under intensive weathering. It involves complete breakdown of the crystal structure. The products of this breakdown are recrystallized to form a new mineral. Recrystallization is evident in following cases:

- Recrystallization occurs in the formation of mineral kaolinite. Kaolinite is formed from solutions rich in silicon and aluminium derived from the breakdown of 2:1 type structure. Thus, more than one type of minerals may be formed.
- Volcanic glass is recrystallized to halloysite through allophanes.

Conditions Suitable for Formation of Individual Clay Minerals

Local parent material and weathering conditions determine the kind of clay minerals found in soils.

- The well drained and well weathered soils of humid and subhumid tropics are dominated by the oxides of iron and aluminium.
- Kaolinite is found with hydrous oxide clays in tropical areas.
- The smectite, vermiculite and fine grained mica are more prominent in areas where weathering is less intense.
- Fine grained micas, are prominent in areas where the parent material or the soil solution surrounding the weathering minerals is high in potassium.

- Parent material high in metallic cations (particularly magnesium) and subject to restricted drainage, encourage smectite formation.

IRON AND ALUMINIUM OXIDES

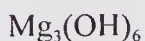
- They are called sesquioxide clays. These are accumulated as a result of loss of silica and aluminium due to leaching. Intensive weathering of minerals in warm humid climates leads to their formation. The main examples are gibbsite $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ and its hydrated form $\text{Al}(\text{OH})_3$ and goethite $\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ and its hydrated form FeOOH . The red and yellow colours of highly weathered soils are attributed to these minerals.
- Gibbsite content in soils is an indication for highly weathered condition. Hematite imparts red colors to tropical and subtropical soils.
- They are amorphous as well as like clays they have crystalline structure. At high pH values, they carry negative charges and attract cations.
- Fe and Al oxides are not as sticky, plastic and cohesive as clays. Thus, soils dominated by them are in a better physical condition.

ORGANIC SOIL COLLOIDS

- Humus is an organic soil colloid. It consists of negatively charged anion (micelle) surrounded by adsorbed cations. (Fig 13.15).
- Humus is amorphous, dark brown to black, nearly insoluble in water. Humus contains about 50% carbon, 5% nitrogen, and lesser amounts of oxygen, sulphur, phosphorus. It has a high cation exchange capacity.
- Soil humus is composed of polymerized aromatic molecules, polysaccharides, bound amino acids and proteins, uronic acid polymers and organo-phosphorus compounds. According to current theories of humus formation, stable polymers of high molecular weight are formed through alteration of plant lignins, tannins and other phenolic substances.
- This process of decomposition is carried out through bacteria and fungi at the initial stage of decomposition, the actinomycetes show their biochemical activity at later stages. Moisture(optimum), aeration(optimum), pH (6–7.5) and temperature (30–45°C) favorably affect the activities of organisms.

Difference between Organic and Inorganic Soil Colloids

- Humus micelle is composed of carbon, hydrogen and oxygen. Clays are composed of aluminium, silicon and oxygen.
- Humus is a complex mixture of amorphous and colloidal organic substances. The size of particles may be as small as the silicate clays. Clays are crystalline.
- Humus is more dynamic in nature, being formed and destroyed more rapidly than clays. Clays on the contrary are static in nature and not subjected to rapid alterations. However, clays change when weathered or attacked upon by weathering agencies.
- Humus colloids are complex and hence their specific structure is not well known. The major sources of negative charges may be partially dissociated methoxyl, carboxylic($-\text{COOH}$), enolic($-\text{OH}$) and phenolic  -OH groups.



Trioctahedral sheet, No substitution, No net charge

Trioctahedral sheet, Al^{3+} substituted for Mg, one excess positive charge

This is common in iron and aluminium oxides found in highly weathered soils in tropics.

Factors Affecting Isomorphous Substitution

Size of the ions: It occurs with ions of almost similar size (ionic radii). It is observed that Na^+ (0.98 Å or 0.098 nm) and Ca^{2+} (0.99 Å or 0.099 nm) are almost of equal size and can replace one another with relative ease. Mg^{2+} (0.066 Å or 0.066 nm) and Fe^{3+} (0.64 Å or 0.064 nm) may substitute for each other. On the contrary, K^+ (1.33 Å or 0.133 nm) because of its much larger size is unable to replace Na^+ or Ca^{2+} . Aluminum (0.51 Å or 0.051 nm) is between Si^{4+} (0.42 Å or 0.042 nm) and Mg^{2+} or Fe^{3+} in size and is capable of replacing any of these. (1 nm = 10^{-9} m) Magnesium and iron ions are also of almost equal sizes and may substitute for each other, the sizes being within 15% difference of one another.

Valence of the ions: The valency between those substituted ions should not differ more than one unit. For example, Na^+ can replace Ca^{2+} in spite of the larger valence of Ca^{2+} . However, ionic “radii” of elements also simultaneously affect it.

Type of clay minerals: This occurs significantly in 2:1 type of clay minerals as the sheets are loosely held and provide enough space for substitution of ions and charges on these minerals are not pH-dependent.

Isoelectric Point of a Mineral

Soil colloids exhibit positive as well as negative charges. Soil clays ordinarily carry an electronegative charge. This makes possible cation exchange in soil. Positive charges arise through addition of H^+ ions (protonation). Anion exchange is possible through positive charges. The H^+ and OH^- are responsible for the development surface charges on soil colloids. They are called potential determining ions. The net surface charge will become zero if the negative charge equals the positive charge. The pH, at which the negative and positive charge become zero (the surface charge is electrically neutral) is called the isoelectric point or zero point of charge pH_0 . For example, the isoelectric point of gibbsite is pH 7.0. At pH values above this pH, the colloid is negatively charged. At pH values below this, the colloid is positively charged.

References and Suggested Readings

- Cresser, M. Killham, K. and Edwards, T. (1993). *Soil Chemistry and its Applications*. Cambridge Environmental Chemistry Series 5, Cambridge University Press, London.
- Grim, R. E. (1953). *Clay Mineralogy*. McGraw Hill Book Co. Inc., New York.
- Marshall, C. E. (1980). *The Physical Chemistry and Mineralogy of Soils*. John Wiley and Sons Inc., New York.
- Raychaudhuri, S.P. (1958). Properties of Colloidal Soil Constituents, *ICAR Research Series No. 17*.

QUESTIONS

Q.1. Fill in the blanks

- i) Colloidal particles are usually smaller than _____ in diameter.
- ii) The migration of colloidal particles under the influence of an electric field is called _____.
- iii) The external surface area of 1 g of colloidal clay is _____ times that of 1 gram of coarse sand.
- iv) Physical properties exhibited by soil colloids are characteristically a _____ phenomena.
- v) Dioctahedral sheet is dominated by _____ and trioctahedral sheet is dominated by _____.
- vi) _____ has sheets of water between layers of kaolinite.
- vii) When there is isomorphous substitution of Al^{3+} for Si^{4+} in the tetrahedral sheet of 2:1 type clay, the minerals so formed is named _____.
- viii) _____ are iron magnesium silicates with some aluminium.
- ix) Allophanes have a chemical composition _____.
- x) _____ is a organic soil colloid.
- xi) Charges on _____ type of clays are usually pH dependent.
- xii) The isomorphous substitution of any cation for one with a lower charge results in an increase in the _____ charge. This is common in _____ oxides.

Answers

(i) 1 micrometer (ii) cataphoresis (iii) 1000 (iv) surface (v) aluminium (Al^{3+}), magnesium (Mg^{2+}) (vi) Halloysite, (vii) Beidellite (viii) Chlorites (ix) $Al_2O_3 \cdot 2SiO_2 \cdot H_2O$ (x) Humus (xi) 1:1 (xii) positive, Fe Al

Q. 2. Choose the correct answer

- i) Heat of wetting can/ can not be used as a method for estimating colloidal content of soil
- ii) Soils containing more than 15/5% clay exhibit plasticity
- iii) Soils dominated by sodium/ calcium or hydrogen have wide variations between their lower and upper plastic limits
- iv) High plasticity is not a desirable/ desirable quality in soils
- v) In montmorillonite/ kaolinite there is considerable isomorphous substitution in the octahedral layer
- vi) Muscovite and Biotite are two main members of 2:1 non expanding / 2:1 expanding, minerals
- vii) Humus/ clay is amorphous , dark brown and nearly insoluble in water
- viii) Most of the negative charge on humus/ clay is pH-dependent
- ix) Isomorphous substitution occurs significantly in 2: 1/ 1:1 type of clays
- x) Isomorphous substitution does not always/ always result in the development of negative charges

Answers

(i) can (ii) 15 (iii) sodium (iv) not a desirable (v) montmorillonite (vi) 2:1 non expanding (vii) Humus (viii) humus (ix) 2:1 (x) does not always.

Q. 3. Define the following

- (i) Electro-osmosis (ii) Chemisorption (iii) Tyndall effect (iv) Brownian movement (v) Plasticity (vi) Specific surface

Q. 4. Differentiate between

- (i) Clay fraction and Clay minerals (ii) Tetrahedral and Octahedral sheet (iii) Nontronite and Saponite (iv) Gibbsite and Brucite structure (v) Muscovite and Biotite (vi) Organic and Inorganic soil colloid (vii) Alteration and Recrystallization

Q. 5. Write short notes on

- (i) Dialysis (ii) Water of hydration (iii) Heat of wetting (iv) Mixed layer minerals (v) Allophanes (vi) Isoelectric point of a mineral (vii) Detrital inheritance

Q. 6. Comment on the following statements

- i) The constituents of the soil which are in colloidal state are the seat of reactions in soil.
- ii) A double diffuse layer is formed around clay micelle.
- iii) Soils dominated by montmorillonite are difficult to handle.
- iv) Swelling and Shrinkage is distinctly exhibited by montmorillonite.
- v) Kaolinite units are tightly bound by hydrogen bonds.
- vi) There is an increase in the interlayer space of montmorillonite.
- vii) Illite is a non expanding clay mineral.
- viii) Soils dominated by Fe and Al oxides are in a better physical condition.
- ix) Soils containing allophanes have phosphate deficiency.
- x) The charges on the exposed crystal edges of 1:1 clay mineral are pH- dependent.
- xi) Isomorphous substitution occurs with ions of almost similar size.
- xii) K^+ is unable to replace Na^+ or Ca^{2+}

Q. 7. Answer the following in brief

- i) Classify soil colloids.
- ii) A cube of 4 cm a side has a surface area of 96 cm². Find the surface area if this cube is cut into two halves (i.e. 2 cm a side) (Answer 192 cm²).
- iii) Classify clay minerals.
- iv) Enlist four examples each of 1:1 type and 2:1 type expanding clay minerals.
- v) What is the mechanism of development of negative charges in 2:1 expanding type clay mineral.
- vi) Enlist with examples the sequence of changes in silicates clay minerals during continuous weathering.
- vii) Explain the mechanism of isomorphous substitution with example.

Q. 8. Answer the following in detail

- i) Compare important properties of kaolinite montmorillonite and illite clay minerals.
- ii) Explain the source of negative charges on clays.

Q. 9. Give diagrammatic view of the following

- (i) Silica tetrahedron (ii) Alumina octahedron (iii) Structure of kaonilite (iv) Structure of montmorillonite (v) Structure of chlorite. □

Ion Exchange Phenomena

NUTRIENTS released in solution during weathering tend to be adsorbed on the humus and clay surfaces. Clay minerals and humus hold anions and cations in exchangeable state. Clay and humus are in a colloidal state, they expose a relatively large surface area for adsorption of water and ions. The cation exchange capacity of the sand and silt fractions is neglected in the approximation of cation exchange since it is too small. The process by which these ions are exchanged between solid and liquid phases or between solid phases if in close contact with each other is termed as ion exchange. The common exchangeable cations are Ca^{++} , Mg^{++} , H^+ , K^+ , NH_4^+ , Na^+ (in order of abundance). The common anions in clay materials are $\text{SO}_4^{=}$, Cl^- , PO_4^{-3} and NO_3^- . Nature and amount of clay, organic matter, soil reaction and mineralogical composition of the soil affect ion exchange. Change in soil pH due to application of liming material decreases rate of ion exchange because of ionization. Organic matter containing more – COOH groups has the capacity of high ion exchange.

It has also been found that the rate of ion exchange is reduced due to organic matter and clay interactions. Ion exchange includes i]. cation exchange ii]. anion exchange. These chemical and physicochemical interactions govern the chemical composition of plant root environment and have effect on short-term nutrient availability to plants. Thus cation exchange behavior of soils is important.

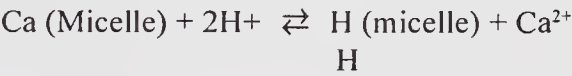
SITE OF CATION EXCHANGE

Cation exchange consists of an interchange between cations adsorbed on the surface of soil and cations in soil solution or those released by plant roots. Likewise, two clay crystals may exchange ions on their surfaces based on their structure. Cations thus held are called adsorbed cations. Various cations adsorbed by soil colloids are subject to replacement through cation exchange. Most of the cations are held on the soil surfaces and only a few ($< 1\%$) are present in soil solution. Thus equilibrium exists between the adsorbed cations with those in soil solution. Changes in the soil solution brought about by fertilizer application or plant removal do not appreciably change its concentration because the adsorbed cations act as a buffer to the solution. Plant growth is affected by many chemical properties, which influence cation exchange.

Mechanism of Cation Exchange

Since clay colloids carry negative charges, cations are attracted to the clay particles. These cations are held electrostatically on the clay surfaces. They are

held by small, negatively charged particles of clay and organic matter called micelles. Micelles can be considered as polyanions because they carry large negative charges. The cations that can be replaced on exchangeable sites by other cations are called exchangeable cations. They are weakly held, in direct contact with the soil solution, and are exchanged fairly easily. Ions that are held very tightly with colloid may be trapped between layers of a clay micelle. They do not pass into the soil solution very easily and are non-exchangeable. Cation exchange takes place when any cation is added to the soil, such as Ca^{++} , K^{+} , or NH_4^{+} through lime, potassic fertilizers or ammonium sulphate respectively. This can be observed if a small amount of soil is leached by a solution of normal ammonium acetate. The filtrate contains exchangeable cations such as Ca^{++} , Mg^{++} , Na^{+} because NH_4^{+} ions have replaced all these cations. Similarly, in soils hydrogen ions generated as organic matter decomposes or by respiration of plant roots can displace calcium and other metallic cations from colloidal complex. This can be shown as follows:



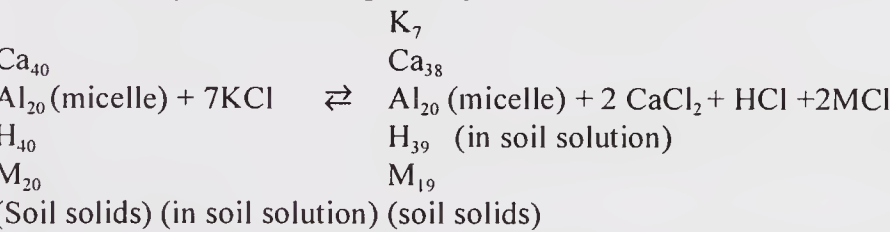
To maintain electroneutrality in the soil, exchange reactions are stoichiometric as shown below:



The reaction takes places rapidly, is reversible and the interchange of calcium and hydrogen is in chemical equivalence. Cation exchange proceeds in different ways depending upon climatic conditions. In areas of low rainfall, calcium and other metallic cations are on the surface of soil as they are not subjected to leaching. In areas with sufficient rainfall, soils tend to become acidic due to leaching of bases.

Addition of Fertilizer

When a fertilizer, for example a potassium fertilizer, KCl is added in soil, many of the numerous potassium ions replace other cations already adsorbed on the exchange sites. The adsorbed potassium remains in an available condition and is not subject to leaching. It may be illustrated as follows:



Calcium, hydrogen, aluminium and metallic cations have been shown in the ratio of 40:40:20:20 respectively. Hydrogen and aluminium are held rigidly on soil complexes and therefore not subjected to losses. Potassium is adsorbed on the soil colloidal complex resulting in loss of equivalent amounts of Ca^{++} and other metallic cations in soil solution.

Influence of Atmospheric Pollution

Nitric and sulphuric acids (produced as a result of atmospheric pollution, acid rains or biochemical processes in soil) result in a shift of ionic exchange

equilibria and enhance leaching of base cations. If the base cations leached from cation exchange sites are replenished subsequently by geochemical weathering, the pH of the soil will not fall and soil may be strongly buffered against pH change for many years.

Clay Humus Complex

The clay-humus complex may have a cation exchange capacity a little less than that of the clay and the humus, if measured separately. The type of humus formed in the soil giving the clay-humus complex depends on the type of clay present. For example, montmorillonite clays under poor drainage form black cotton soils and their colour is due to clay-humus complex. Kaolinite and red earth clays are better drained sites. Clay-humus complex is formed under conditions of good calcium supply and high to medium CEC clays. Two types of clay-humus complex exist. The first is due to attraction of negatively charged humic colloids for the positively charged sites on the soil surface. The second is soil matrix-clay humate complexes thought to form when humates are adsorbed to clay minerals by polyvalent cations such as Ca^{2+} and Fe^{3+} and by associations with hydrous oxides (through coordination or anion exchange).

Equations of Cation Exchange

The adsorption equation of Freundlich and Langmuir: It may be used to express ionic composition in the soil solution for adsorption reactions in a narrow range.

$$x = kC^{1/n}$$

Where x = amount of cations adsorbed per unit amount of adsorbent

C = equilibrium concentration of the added cation

k, n = constants

The langmuir equation:

$$\frac{x}{x^\circ} = \frac{KC}{1 + KC}$$

Where x = amount of cations adsorbed per unit weight of exchanger

x° = total exchange capacity

C = concentration of added cations in moles l^{-1}

k = affinity coefficient (constant)

k is derived as follows:

$$x(1 + kC) = x^\circ kC$$

$$x + xkC = x^\circ kC$$

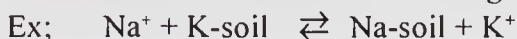
$$x = x^\circ kC - xkC$$

$$x = kC (x^\circ - x)$$

Therefore,

$$kC = \frac{x}{x^\circ - x}$$

Gapon equation: The equation can apply for a
Monovalent-monovalent cation exchange reactions



Application of the mass action law gives:

$$\frac{[\text{Na}^+] (\text{K}^+)}{(\text{Na}^+) [\text{K}^+]} = K_{\text{eq}}$$

or

$$\frac{(\text{K}^+)}{(\text{Na}^+)} = K_{\text{ex}} \frac{[\text{K}^+]}{[\text{Na}^+]}$$

The sign [] denotes adsorbed ions, whereas () denotes free ions in solution. The equilibrium constant K_{eq} becomes K_{ex} , which is often called selectivity coefficient.

The value of K_{ex} indicates the tendency that one cation is adsorbed more over the other. When,

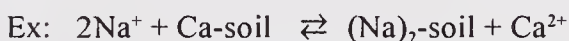
$$K_{\text{ex}} = \frac{(\text{K}^+)}{(\text{Na}^+)}$$

Then;

$$\frac{[\text{K}^+]}{[\text{Na}^+]} = 1.0$$

This means that equal amounts of K^+ and Na^+ ions are adsorbed.

Mono- divalent cation reaction



At equilibrium,

$$\frac{[\text{Na}^+] (\text{Ca}^{2+})}{[\text{Ca}^{2+}] (\text{Na}^+)^2} = K$$

The signs [] and () again denote adsorbed and free ions, respectively. Confirming to the law of mass action, the equation states that the ratio of the activity product of reaction products and that of the reactants is constant. By taking the square root,

$$\frac{[\text{Na}^+] (\sqrt{\text{Ca}^{2+}})}{[\sqrt{\text{Ca}^{2+}}] (\text{Na}^+)} = k$$

This equation is also known as the Gapon equation.

Equations based on the Donnan theory: A Donnan system is a system composed of solution I and O, separated by a semipermeable membrane (I=inside solution, O= outside solution)

<i>Solution I</i>		<i>Solution O</i>
Na ⁺		Na ⁺
Cl ⁻		Cl ⁻
Na-clay		
Semipermeable membrane		

Solution I contains Na⁺ and Cl⁻ and Na-clay, whereas solution O contains only Na⁺ and Cl⁻ ions of different concentration from those in solution I. The membrane is permeable only to Na⁺ and Cl⁻ ions; therefore, only those ions will move and distribute themselves in solution until equilibrium is reached. At equilibrium,

$$\begin{aligned} (\text{Na}^+)_i (\text{Cl}^-)_i &= (\text{Na}^+)_o (\text{Cl}^-)_o \\ \text{or} \\ \frac{(\text{Na}^+)_i}{(\text{Na}^+)_o} &= \frac{(\text{Cl}^-)_o}{(\text{Cl}^-)_i} \end{aligned}$$

Donnan systems are present in soils and are of special importance in soil solution - plant root relationships, Donnan systems have been applied to cation exchange phenomena

$$\frac{[\text{Na}]^2 (\text{Ca}^{2+})}{(\text{Na}^+)^2 [\text{Ca}^{2+}]} = K$$

Donnan assumes $k=1$; therefore the equation change Δ into

$$\begin{aligned} \frac{[\text{Na}^+]^2 (\text{Ca}^{2+})}{(\text{Na}^+)^2 [\text{Ca}^{2+}]} &= 1 \\ \text{or} \\ \frac{[\text{Na}^+]}{(\text{Na}^+)} &= \frac{[\sqrt{\text{Ca}^{2+}}]}{(\sqrt{\text{Ca}^{2+}})} \end{aligned}$$

Schofield's ratio law: It may be seen in all reactions involving cation exchange that the ratios of the products of adsorbed cations and cations free in solution are constant. This can be illustrated by mass action and Gapon equations:

$$\frac{[\text{Na}^+] (\sqrt{\text{Ca}^{2+}})}{[\sqrt{\text{Ca}^{2+}}] (\sqrt{\text{Na}^+})} = k$$

In which [] denotes adsorbed ions, and () denotes ions in solution. Rearranging the equation gives

$$\begin{aligned} [\text{Na}^+] (\sqrt{\text{Ca}^{2+}}) &= k [\sqrt{\text{Ca}^{2+}}] (\text{Na}^+) \\ \text{or} \\ \frac{(\text{Na}^+)}{[\sqrt{\text{Ca}^{2+}}]} &= \frac{1}{k} \frac{[\text{Na}^+]}{(\sqrt{\text{Ca}^{2+}})} \end{aligned}$$

This means that in equilibrium condition, the ratio of cations in solution depend on the ratio of cations adsorbed on the colloidal surface. If the amount of cations adsorbed does not change significantly or remain constant, the ratio of cations in solution (Na^+)/(Ca^{2+}) is also constant. The activities of all monovalent cations are changed in one ratio, those of the divalent in the square and those of all trivalent in the cube of that ratio. This is called the ratio law given by Schofield (1947). The ratio law is used to predict the soil solution concentration as affected by fertilizers, lime application, or dilution by irrigation or rain. Thus, upon dilution the Na^+ concentration decrease two times, the value of $\sqrt{\text{Ca}^{2+}}$ concentration must also decrease two times to obey the ratio law. This means that Ca^{2+} concentration then decreases 2^2 times. Hence, dilution favours a decrease in Ca content.

Fixation of Cations

Some adsorbed cations are held so strongly by clays that they cannot be released by exchange reactions. These cations are called fixed cations. Fixation of K^+ and NH_4^+ is more important and occurs by a similar mechanism. These cations are entrapped in intermicellar space of the clays. Expanding clays have octahedral holes of $1.40 \text{ \AA}$. When K^+ or NH_4^+ penetrates the intermicellar space, they will fit snugly into the holes. Upon closure, K^+ or NH_4^+ ions are trapped between the clay layers. They become relatively non-exchangeable and are called fixed. Presence of humic and fulvic acids in soils may accelerate the release of K^+ and NH_4^+ ions. Continued application of K^+ or NH_4^+ fertilizers will decrease K-fixation. The addition of K will fill the vacant position in the clay lattice, thus satisfying the fixation capacity of soils.

CATION EXCHANGE CAPACITY

The exchange property that seems to be important for use as a differentiating criterion in categorising soils is the CEC of the soil. This property is a measure of the exchange capacity of the clay minerals, humus and other associated minerals. Exchange capacity consists of negative charges. Negative charges may be permanent or pH- dependent. The permanent charges occur in clays and result from isomorphous substitution within the clay structure and is highest in 2:1 clays. The pH - dependent charges are related directly to soil pH. At low pH values, the charges and CEC is low but increases as the pH rises. Both mineral and organic materials have pH- dependent charges. Both these groups (mineral and organic materials) possess covalent bonded hydrogen ions which can be dissociated at high pH developing a negative charge. Tightly adsorbed aluminium and iron in 2:1 clays block some of the negatively charged sites, thus reducing the CEC. With an increase in pH, the aluminium and iron are removed and the sites become available. In tropical climate the CEC in soils is generally low because of the presence of large amounts of kaolinite and 1:1 minerals.

Cation Exchange Capacity Defined

Cation exchange capacity is defined as the sum total of the exchangeable cations that a soil can adsorb. The cation exchange capacity is expressed in terms

of moles of positive charge per unit mass, as centimole per kg of soil (cmol/kg). One mole of charge is provided by 1 mole of monovalent cation, by 1/2 mole of divalent cation (like $\text{Ca}^{2+} + \text{Mg}^{2+}$) or by 1/3 mole of trivalent cation (like Al^{3+}). Thus, if a soil has a cation exchange capacity of 20 cmol/kg 1kg of the soil is capable of adsorbing 20cmol of H^+ ion or 10 cmol of Ca^{++} or Mg^{++} ions and so on. Thus 1 mole of charge associated with H^+ ion is replaced by the equivalent charge associated with 1/2 mole of Ca^{++} .

Question: Calculate the amount of CaCO_3 needed to replace 20 cmol/kg of exchangeable ions from a soil.

Solution ∴

Therefore, 1 mole of H^+ ion weighs = 1 g
and 1/2 mole of Ca^{++} ion weighs = $40/2 = 20$ g
Thus to displace 1 centimol of H^+ ion/kg of soil = $20/100=0.2\text{g Ca}^{++}/\text{kg soil}$
Amount of Ca^{++} required for one hectare of furrow slice= $0.2\times 2.2 \times 10^6 = 440$ kg
Therefore, Amount of CaCO_3 needed = $440 \times 2.5 = 1100$ kg

Question : In a soil, determination of exchangeable cations and anions give the following results. Find the CEC.

Cations	Cmol/kg Soil	Anion	Cmol/kg Soil
Na^+	5	Cl^-	1.0
K^+	3	$\text{CO}_3^{=}$	0.3
Ca^{++}	10	HCO_3^-	0.7
Mg^{++}	7		
H^+	3		
Σ cations	28	Σ anions	2.0

CEC = Σ exchangeable cations – Σ exchangeable anions
= $28 - 2$
= 26

Determination of Cation Exchange Capacity

Cation exchange capacity is usually determined at a constant pH. This is because of the existence of the pH – dependent negative charge on the surface of organic colloids and the 1:1 type of clay minerals. Method of estimation of cation exchange capacity depends upon the method of saturation used. Cation exchange can be measured by following method:

- By leaching the soil with neutral N- ammonium acetate. The ammonium rapidly displaces substantial amounts of other cations. The excess of ammonium acetate is removed by washing with alcohol. The adsorbed ammonia is displaced and distilled with MgO. The ammonia is adsorbed in standard acid (N/10) solution. The excess of acid is titrated with standard alkali (N/10). This can be illustrated by following reactions:

- $\text{CH}_3\text{COONH}_4 \rightleftharpoons \text{NH}_4^+ + \text{CH}_3\text{COO}^-$
- $\text{X-soil} + \text{NH}_4^+ + \text{CH}_3\text{COO}^- \rightarrow \text{NH}_4\text{-soil} + \text{CH}_3\text{COOX}$
- $\text{MgO} + \text{H}_2\text{O} \rightarrow \text{Mg(OH)}_2 \rightarrow \text{Mg}^{2+} + 2(\text{OH})^-$
- $2 \text{NH}_4\text{-soil} + \text{Mg}^{2+} + 2(\text{OH})^- \rightarrow 2\text{NH}_3 + \text{Mg-soil} + 2 \text{H}_2\text{O}$
- The soil is leached with a sodium acetate solution (pH 8.2) for replacement of exchangeable cations by Na^+ ions. The excess of salts are washed down by alcohol and the adsorbed Na^+ ions are replaced by NH_4^+ ions, using $\text{N-CH}_3\text{COONH}_4$ (pH7) solution. The Na^+ ions so released from the exchange spots are measured flame photometrically and serve as the measure of total exchange capacity of the soil. This can be illustrated by following equations:
 - $\text{CH}_3\text{COONa} \rightleftharpoons \text{CH}_3\text{COO}^- + \text{Na}^+$
 - $\text{X-soil} + \text{Na}^+ + \text{CH}_3\text{COO}^- \rightleftharpoons \text{Na-soil} + \text{CH}_3\text{COOX}$
 - $\text{CH}_3\text{COONH}_4 \rightleftharpoons \text{CH}_3\text{COO}^- + \text{NH}_4^+$
 - $\text{Na-soil} + \text{NH}_4 \rightleftharpoons \text{NH}_4\text{-soil} + \text{Na}^+$

FACTORS AFFECTING CATION EXCHANGE CAPACITY

Cation exchange capacity is affected by soil pH, humus and clay contents and can be predicted approximately if their values are known.

Soil texture: The charge at the surface of particles of any specified composition will increase with the surface area exposed, which in turn increases with a decrease in the mean particle diameter. Thus, other factors being equal, smaller the particles, greater the surface area and greater the cation exchange capacity. The particle size distribution of mineral grains is of great relevance to its cation exchange properties. Cation exchange capacity increases with fineness of soil particles i.e. with increasing percentage of clay (Table 14.1). This is because negatively charged clay micelle attracts positively charged cations.

Organic matter: In general, cation exchange capacity increases with organic matter content of soil. Humus micelle is negatively charged and is capable of holding nutrient ions. The dissociation of phenolic (-OH) and carboxylic acid (-COOH) groups on soil organic matter is strongly pH- dependent, thus cation exchange capacity varies with pH in many soils. Hence negative charge on a humus micelle depends on pH. When the pH increases, more H^+ ions dissociate from the groups. Consequently, the negative charge on the humus micelle increases.

Nature of clay: Cation exchange capacity of clay mineral varies. Soils dominated by vermiculite and montmorillonite clays have greater cation exchange capacity than those dominated by kaolinite, illite or chlorite minerals. C.E.C. of

Table 14.1. Cation exchange capacity of different texture classes

Soil textural class	CEC (Cmol /kg)
Sand	0-5
Fine sandy loam	5-10
Loam, silt loam	5-15
Clay loam	15-30
Clay	>30

Table 14.2. Cation exchange capacity of important clay minerals

MINERAL	C.E.C. cmol/kg	Contribution made by each per cent of clay
Montmorillonite	100	0.6 – 1.0
Vermiculite	150	0.8 – 1.4
Illite	30	0.1 – 0.4
Chlorite	30	0.1 – 0.4
Kaolinite	8	0.02 – 0.10
Fe, Al oxides	4	0.05

important clay minerals and contribution made by each percentage of clay is given in Table 14.2.

Soil reaction: In general, CEC increases with increasing pH. At low pH, only permanent charges of clays and organic colloids hold ions. As the pH increases, hydrogen held by clay and organic colloid becomes ionized and is replaceable. Secondly, aluminium hydrogen ions which are adsorbed at low pH, are released forming $\text{Al}(\text{OH})_3$, thereby releasing additional exchange sites on the colloids. This results in an increase in negative charge and an increase in the CEC. As much as 20–40% of the CEC may be from pH-dependent sites. As the pH rises, pH-dependent CEC also increases. Most CEC from humus is pH-dependent (Fig 14.1).

Nature of cations and their power of replacement: Cations are adsorbed on clay or humus with different degree of tenacity. It has been shown that replacing power of cations increases with the atomic weight. Thus potassium ion (at.wt.39) is a powerful replacer than sodium ion (at.wt.23). Potassium is readily adsorbed by clay than sodium. Divalent cations are adsorbed more strongly than monovalent cations on the clay and humus complexes, thus they will be exchanged with more difficulty in comparison to monovalent ions. Hydrogen is an exception. Hydrogen ions are adsorbed more strongly than any other monovalent or divalent ions. Hydrogen clays prepared by exchange reactions initially contain large amounts of exchangeable H^+ ions and small amounts of Al^{3+} ions. However, the concentration of exchangeable Al^{3+} ions builds up rapidly. The exchangeable H^+ ions cause a partial decomposition, and Al^{3+} released from the clay becomes exchangeable. In general, the power of replacement is, $\text{H} > \text{Ca} > \text{Mg} > \text{K} > \text{Na}$. The solubility of each cation is regulated by its relative contribution to the total cation exchange population, thus calcium solubility is regulated by the ratio of exchangeable calcium to CEC. Assume that a soil has equal number of calcium and sodium ions. Calcium will tend to take over the other exchange sites because it adsorbs more strongly on the micelle. Sodium will tend to leach out of the solution.

Size of ion: The relative abundance of calcium and magnesium is more than sodium and potassium. Generally, ions with smaller hydrated sizes are adsorbed in preference (Table 14.3). The following order of preference for adsorption of monovalent cations by clays has been reported: $\text{Cs} > \text{Rb} > \text{K} > \text{Na} > \text{Li}$, Cesium is the smallest in size, thus its rate of adsorption is highest. A thick hydration cell of lithium increases the distance from ion to the clay surface.

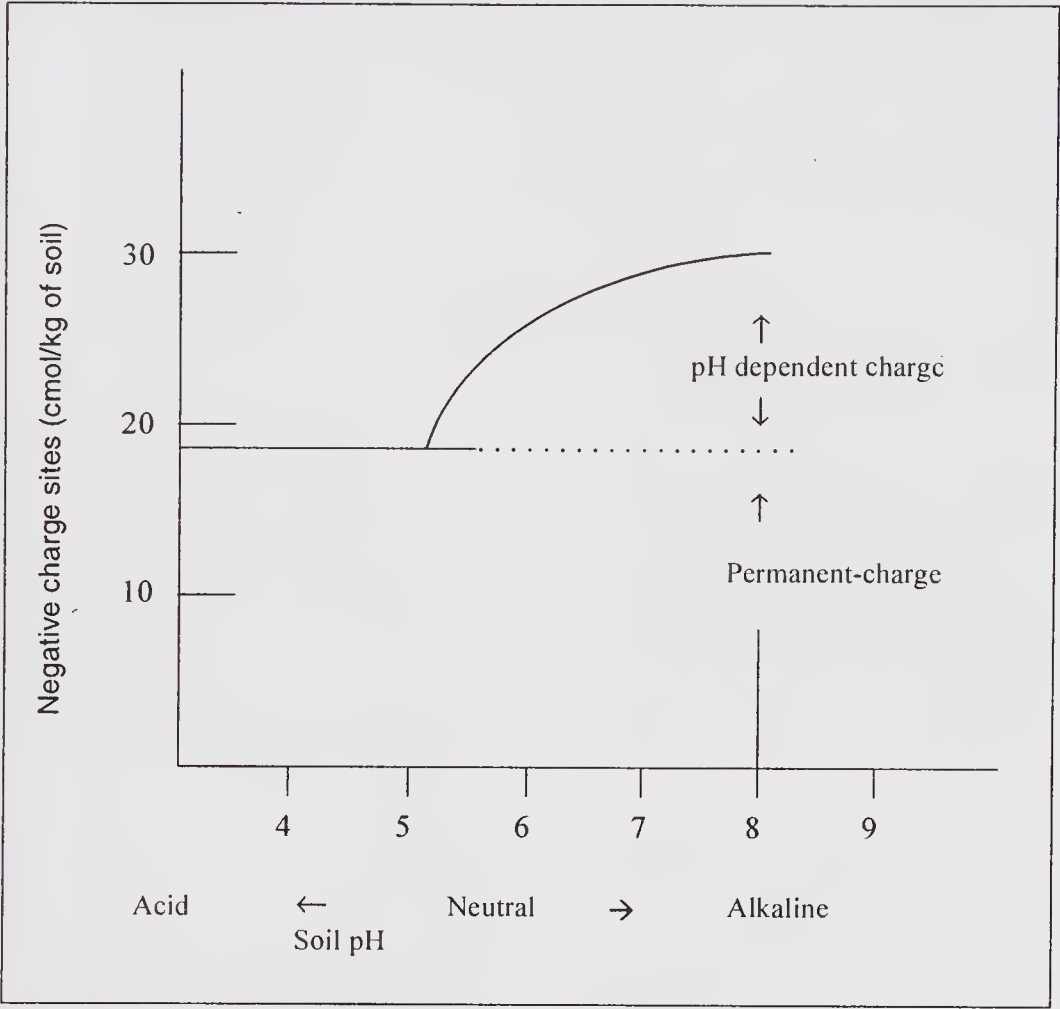


Fig. 14.1. Effect of pH on negative charges of colloids

BASE SATURATION

Base saturation is a measure of the extent to which the exchange complex is saturated with basic cations. Base saturation depends on the rainfall and nature of parent material. As the cation content increases there is a tendency for sodium to increase and it is dominant in soils of arid and semi-arid areas.

Soil exchange complex consists of basoids (base forming substances) and acidoids (acid forming substances). Basoids consists of cations like Ca^{++} Mg^{++} Na^{+} and K^{+} . Acidoids consists of hydrogen and aluminium (H^{+} and Al^{3+}) as they

Table 14.3. Ionic radii and hydration of cations (radii of ions in Angstroms (10^{-8} cms))

	Dehydrated	Hydrated
Lithium	0.78	10.03
Sodium	0.98	7.90
Potassium	1.33	5.32
Rubidium	1.49	5.09

contribute to acidity either directly as hydrogen ions in soil solution or through hydrolysis as Al^{3+} ions forming aluminium hydroxides.

Per cent Base Saturation

The proportion of CEC occupied by bases in percentage is called percent base saturation. (pbs)

$$\text{Per cent base saturation (pbs)} = \frac{\text{Exchangeable bases (cmol/kg soil)}}{\text{CEC (cmol/kg soil)}} \times \frac{100}{1}$$

For example, a soil has a CEC of 20 cmol/kg and 5 cmol of these cations are aluminium and hydrogen, the remaining cation exchange sites contain the basic cations i.e. 15 cmol/kg or 75%. Consequently, if the percentage base saturation is 66, it shows that 2/3 of the CEC is satisfied by bases and 1/3 by hydrogen and aluminium. Knowledge of percentage base saturation is useful in following ways: i) Percentage base saturation helps in the calculations of amount of lime needed to raise the pH of acidic soils ii) It is a good index of the proportion of plant nutrient in CEC of soil. The base saturation is an index of soil fertility. iii) The ease with which adsorbed cations are released to plants depends on the degree of base saturation. iv) Soil is considered very fertile if the pbs is > 80, medium fertile if pbs is between 80–50 and non fertile if pbs is ≥ 50 .

Liming is the common means by which the pbs of soils is increased.

Base Saturation and pH

There is a definite correlation between base saturation and pH. Thus if pH is determined the base saturation can be estimated. An increase of 5% base saturation for every 0.1 change in pH has been found in the pH range between pH 5.0 to 7.5. Thus if the percentage base saturation is 70 at pH 7.2, it will be approximately 85 at pH 7.5 and 60 at pH 7.0. In general, soils of semi-arid regions are 90-95% base saturated in comparison to 60–70% of soils of humid regions, since bases are subjected to leaching and there is a dominance of hydrogen and aluminum under these conditions. There might be certain variations to the above rule. Since soils have 100 times more cations adsorbed on the micelles in comparison to those in solution, only the active part of hydrogen ions is measured in the pH. There is a continuous exchange between adsorbed ions and those present in soil solution. pH change depends upon the nature of dominant clay minerals. For examples kaolinite has a pH of 7 at 60% base saturation, but the pH of montmorillonite at the same base saturation is below 5. Montmorillonite acquires pH 7 at 95% base saturation. This is because a higher percentage of H^+ ionizes from montmorillonite than from kaolinite and secondly montmorillonite contains a larger number of all kinds of ions as is evident from its high CEC. Percentage base saturation indicates the amount of exchangeable hydrogen and aluminum ion species present. Soil pH is also affected by the type of cation dominant, for example, in soils with same base saturation; those containing sodium will have higher pH than those dominated by calcium and magnesium.

EXCHANGEABLE CATIONS AND PLANT NUTRITION

Adsorption by Plant Roots

Plant roots absorb nutrients from the soil in the form of cations and anions. Cation uptake is a base exchange process. Cation exchange and adsorption are of great practical significance in nutrient uptake by plants, soil fertility, nutrient retention and fertilizer application.

Plants differ in their power of taking up some cations. In general, uptake of sodium and magnesium is much more as compared to other cations. Halophytes take up large quantities of sodium while maize, wheat and sunflower could take only a little. All plants have about the same power of accumulating potassium when growing in potassium rich conditions. In general, plants differ considerably among themselves in the proportions of potassium, magnesium, calcium and sodium their leaves contain when they are growing in the same soil. They also differ in the minimum and maximum concentration of these ions needed for their healthy growth. It is possible to predict, from the knowledge of the composition of the exchangeable ions in the soil, the concentration of these ions in the leaves of the crop. It has been found that the ratio of potassium to calcium is higher in the leaf than in the soil. The factors for converting from the soil ratio to the plant ratio is dependent on the plant and not on the soil.

Effect of Soil Solution

Capacity of a soil to exchange cations is the best single index of soil fertility. The soil water containing soluble salts and nutrient ions is known as soil solution. It exchanges nutrient cations with hydrogen ions generated by root hairs. If the root hairs are in close contact with the clay and humic micelle under natural conditions than the nutrient ions pass directly from the clay and humic micelle to the root hairs and hydrogen ions without either of these ions coming in contact with the soil solution. This process is called contact exchange. Nutrients added to the soil in the form of fertilizers, will be retained by the colloidal surfaces and prevented from leaching. In general, the adsorption complex is considered to provide soil storage for cations.

Influence of Ions

Availability of nutrients to plants is influenced by:

Nature of ion: The nature and content of exchangeable bases influence soil properties.

Type of cation: A calcium-dominated soil is granular, porous, ensures good aeration and drainage. Na-clay is deflocculated, sticky, difficult to work, has poor drainage and aeration. The cations Ca^{++} Mg^{++} K^+ and NH_4^+ are held on the colloidal surfaces and are readily available to plants.

Atomic weight and valency of cation: This influences the release of cations since all cations are not adsorbed with the same tenacity (see factors affecting CEC).

Nature of clay: Montmorillonite adsorb divalent cations more strongly whereas kaolinite adsorb monovalent cations with greater tenacity. Thus, divalent

cations are readily available to root hairs in soils dominated by kaolinite clay and monovalent cations to soils dominated by montmorillonite clay.

Associated ions: The uptake of a given cation is influenced by ions in association with it. For example, potassium availability to plants is limited by excessive calcium.

Percentage saturation of the clay: When the percentage saturation of the cation in question increases, it becomes available, relatively easier and vice versa. For example, a soil of CEC, 20 cmol/kg with Ca^{2+} ions 10 cmol/kg has base saturation 50%. On the contrary, a soil with CEC, 15 cmol/kg and Ca^{2+} ions 10 cmol/kg will have a base saturation of 66.6%. In such solution, calcium will be relatively easily available in later soil, though it has the same concentration of Ca^{++} ions as the other soil.

PRACTICAL IMPLICATIONS OF CATION EXCHANGE

Soil Fertility

Cation exchange is an important component of soil fertility. The cation exchange capacity values of the clay minerals and humus can be used for calculating approximate cation exchange capacity of a soil of known composition. For example, each per cent of humus contributes 2 cmol of CEC./ kg soil since humus has a CEC of about 200 cmol/kg. In a similar way, 1% of montmorillonite (CEC 100 cmol/kg) contributes 1 cmol/kg and 1% of kaolinite (C.E.C 8 cmol/kg) contributes 0.08 cmol/kg of soil.

Application of Fertilizers

Soluble inorganic fertilizers like ammonium sulfate or ammonium nitrate when applied to soil, their ammonium or nitrate are adsorbed on the surface of colloids by cation exchange. Ammonium ions may be taken up as such or first nitrified to nitrate and then adsorbed by plants. Exchangeable potassium and magnesium are the major source of plants available is K^+ and Mg^{++} . This is of great practical significance, otherwise leaching losses would not allow to make best use of water soluble fertilizers. CEC is invaluable when assessing the fate of fertilizers applied to a soil. Soils with high CEC store more cationic nutrients. Thus fertilizer can be supplied at a single time in such soils as they hold nutrients. Fertilization should be split on coarse textured soils to avoid leaching of fertilizer.

Effect of Cations

Dominance of calcium in the exchange complex has desirable physical conditions and favorably influences microbial activities, ammonification and nitrification. Cation exchange sites hold Ca^{2+} Mg^{2+} K^+ NH_4^+ ions and do not permit their losses.

Toxic Ions

Cation exchange sites adsorb metals like cadmium (Cd^{2+}), nickel (Ni^{2+}) and lead (Pb^{2+}), which when in direct contact with plant roots, may be harmful. Later, these toxic metals may be removed by percolating waters.

pH Effects

It is well known that pH affects availability of plant nutrients. The Na-clay is alkaline and H-clay is acidic. The amount of lime required to raise the pH of an acidic soil depends on CEC of soil. The CEC of a soil is of vital importance in assessing the amount of acidity stored in it. Much more lime is needed to correct the acidity of finer textured soils. (because of their greater buffering capacity)

Use of Amendments in Problematic Soils

- Knowledge of cation exchange helps in the reclamation of saline alkali and acidic soils. Suitable amendments or management practices for their reclamation may be adopted.
- CEC is one of the factors that determine how much herbicide should be spread on the soil. Clay and humus tie up many chemicals. Thus high rate is recommended for finer textured soils to compensate for the amount that will be adsorbed in such soil.

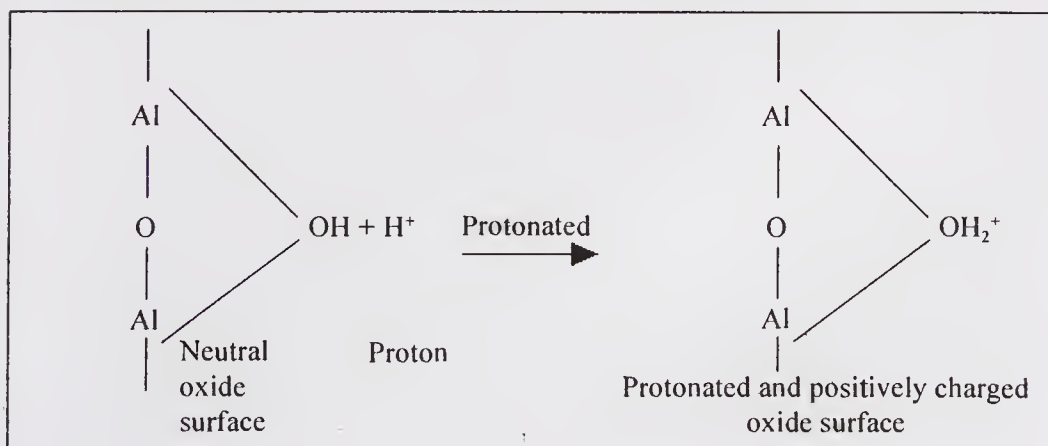
ANION EXCHANGE

Anion Exchange Defined

Replacement of one anion by another anion on the positively charged colloids is called anion exchange. Positive charges are associated with hydrous oxides of iron and aluminium, 1:1 type clays and amorphous materials such as allophanes. For example, Gibbsite, an allophane oxide clay, acquires positive charges. Gibbsite consists of aluminium in six coordination (aluminium in octahedral position) surrounded by six hydroxyls. In highly weathered tropical soils, the hydroxyls take on hydrogen atoms (protonated) as below:

Anion exchange Versus Cation Exchange

- In contrast to cation exchange, phenomenon of anion exchange is much pH dependent. The capacity for holding anions increases with the increase in the acidity. The lower the pH, the greater is the anion adsorption.
- Anion exchange sites are the opposite of cation exchange sites where hydrogen is lost from a hydroxyl group. At the anion exchange sites, an extra hydrogen joins the hydroxyl group to produce a net positive charge. The positive charge can attract anions.
- Site of anion exchange : Clay minerals can take up anions from acid solutions,

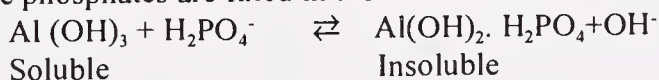


since their broken edges acquire a positive charge due to the adsorption of hydrogen ions in excess. Anions may replace OH groups in clay minerals. These groups are more plentiful in the kaolinite minerals. Broken edge of kaolinite minerals acquire a positive charge on the oxygen (O^-) or OH^- ions on their surface edges. Soils containing kaolinite possess a higher anion exchange capacity than those dominated by montmorillonite or illite. The number of positive charges, which a soil carries, can be determined if the soil is treated with a salt whose anion is strongly adsorbed on these positive sites. The phosphate anion fulfils these conditions. Phosphate is held very strongly on these sites. Soils high in organic matter have the ability to hold anions in an exchangeable form. The relative order of anion exchange is,



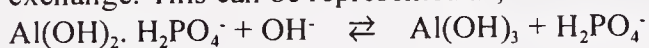
Importance of Anion Exchange

- The phenomenon of anion exchange is important, for the release of fixed phosphate in the soil. Phosphates are held strongly in acid soils. Large amounts of soluble phosphates are fixed in the soil as follows:



Phosphate anions can be attracted to soil constituents with such a bond that they become insoluble. This process is called phosphate fixation.

- Liming of acid soils increases availability of phosphorus because of anion exchange. This can be represented as,



In this equation, $H_2PO_4^-$ has been replaced by OH^- .

Extraction of available phosphorus by Olsen's method using M/2 $NaHCO_3$ with pH 8.5 is based on the principle of anion exchange by OH^- ions.

- iii) Exchange of NO_3^- and Cl^- can be presented as,



Like cation exchange anion exchange is also reversible and rapid phenomena and occurs in chemical equivalence.

References and Suggested Readings

- Bear, F. (1964). *Chemistry of the Soil*, 2nd edn. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi.
- Cresser, M. Killham, K. and Edwards, T. (1993). *Soil Chemistry and its Applications*. Cambridge Environmental Chemistry Series 5. Cambridge University Press, London.
- Kanwar, J.S. and Grewal, J.S. (1971). *A Review of Phosphorus Fixation in Soils of India*. ICAR, Technical Bulletin (Agric.) No. 29.
- Russel, E.W. (1950). *Soil Conditions and Plant Growth*. Longmans, Green and Co., New York.

QUESTIONS

Q. 1. Fill in the blanks

- i) Most of the cations are held on soil surfaces and only few (less than 1 per cent) are present in _____.
- ii) If a small amount of soil is leached by a solution of normal ammonium acetate, the filtrate contains exchangeable cations such as Ca^{++} , Mg^{++} , Na^+ , because _____ ions have replaced all these cations.
- iii) If a soil has C.E.C. of 20 cmol/kg, 1kg of this soil is capable of adsorbing _____ of H^+ ion or 10 cmol of _____ ion.
- iv) The CEC of vermiculite is _____ cmol/kg of soil.
- v) The CEC of chlorite is _____ cmol/kg of soil.
- vi) Al^{3+} ions contribute soil acidity through _____.
- vii) Soil exchange complex consist of basoids and _____.
- viii) Capacity of a soil to exchange cations is the best single index of _____.
- ix) Potassium availability to plants is limited by excessive _____.
- x) Liming of acid soils increase availability of phosphorus because of _____ exchange.
- xi) In general, soils of semiarid regions are _____ % base saturated in comparison to 60-70% of soils of humid region
- xii) in general, each percentage of humus contributes about _____ cmol/kg of C.E.C.

Answers

(i) soil solution (ii) NH_4^+ (iii) 20 cmol, divalent (iv) 150 (v) 30 (vi) hydrolysis (vii) acidoids (viii) soil fertility (ix) calcium (x) anion (xi) 80-90 (xii) 1.5-2.0

Q. 2. Choose the correct answer

- i) Micelles can be considered as polyanions/polycations because they carry a large number of negative charges
- ii) Montmorillonite/ kaolinite dominated soils are better drained
- iii) Continued application of K^+ or NH_4^+ fertilizers will decrease/ increase K-fixation
- iv) The permanent negative charges result from isomorphous substitution/ exposed crystal edges
- v) A thick hydration cell of lithium increases/ decreases the distance from ion to the clay surface
- vi) Positive/ negative charges are associated with hydrous oxides of iron and aluminium
- vii) Percentage base saturation indicates / does not indicate the amount of exchangeable hydrogen and aluminium
- viii) The factors for converting nutrient from the soil ratio to the plant ratio is dependent on the plant / soil
- ix) Soils with high C.E.C. store / does not store nutrients well.

Answers

(i) polyanions (ii) kaolinite (iii) decrease (iv) isomorphous substitution (v) increases (vi) positive (vii) indicates (viii) plant (ix) store

Q. 3. Define the following

(i) Cation exchange capacity (ii) Percentage base saturation (iii) Fixed cations (iv) Anion exchange

Q. 4. Differentiate between

(i) Adsorbed cations and Exchangeable cations (ii) Permanent and pH dependent charges (iii) Cation and Anion exchange

Q. 5. Write short notes on

(i) Adsorption equation of Freundlich and Langmuir (ii) Gapon equation (iii) Schofield's ratio law (iv) Importance of anion exchange (v) Importance of base saturation (vi) Contact exchange

Q. 6. Comment on the following statements

- i) An equilibrium exists between the adsorbed cations and those in soil solution.
- ii) Two types of clay-humus complex exist
- iii) C.E.C. increase with increasing pH
- iv) C.E.C. is low in soils of tropical climate
- v) C.E.C. is determined at a constant pH, usually 7.0
- vi) Base saturation differs with the type of dominant clay mineral present
- vii) In nature, soil pH is buffered in spite of leaching of bases
- viii) There is a definite correlation between base saturation and pH
- ix) Divalent cations are readily available to root hairs in soils dominated by kaolinite clay and monovalent cations to soils dominated by montmorillonite clay
- x) When the percentage saturation of the cation increases, it becomes available relatively easier
- xi) Cation exchange capacity values of clay minerals and humus can be used for calculating approximate C.E.C. values of soils of known composition of clay minerals and humus
- xii) Soil containing kaolinite minerals possess a higher anion exchange capacity than those dominated by montmorillonite or illite as the chief mineral
- xiii) Potassium is adsorbed to clays in preference to lithium
- xiv) Montmorillonite acquire pH 7 at 95% base saturation whereas kaolinite at a similar pH values has 60% base saturation
- xv) Cation exchange behaviour of soils is important
- xvi) Cation exchange minimizes toxic effects of metal ions

Q. 7. Answer the following in brief

- i) Explain the mechanism of cation exchange
- ii) Explain the mechanism of cation exchange when potassic fertilizers are added in soil complex

- iii) What is the principle in the determination of cation exchange capacity (a) using normal ammonium acetate as extractant (b) using distillation method with MgO
- iv) Calculate the amount of CaCO_3 needed to replace 30 cmol/kg of exchangeable ions from a soil
- v) Enlist the order of anion exchange of a few important anion in soil
- vi) How are clay complex formed
- vii) How does phosphate fixation takes place in soil

Q. 8. Answer the following in detail

- i) Explain the principal usefulness of phenomena of cation exchange from different points of view
- ii) Explain the factors affecting cation exchange capacity of a soil

Q. 9. Give diagrammatic view of the following

- i) Effect of pH on negative charges of colloids.



15

Soil Reaction

THE soil reaction describes the degree of acidity or alkalinity of a soil. Water molecule is very stable and dissociates as : $H_2O \leftrightarrow H^+ + OH^-$

The extent to which water ionizes can be expressed in terms of an ionization constant, K_w . Thus $K_w = (H^+) (OH^-) \dots$ (Eqn. 1)

Where, (H^+) and (OH^-) are concentration of hydrogen and hydroxyl ions expressed as equivalents per litre. The value of K_w is 10^{-14} at $22^\circ C$; that is, the product of the concentrations of H^+ and OH^- ions is 10^{-14} .

Eqn.1 can be written as,

$$\log \frac{1}{K_w} = \log \frac{1}{H^+} + \log \frac{1}{OH^-} = 14 \dots \text{(Eqn. 2)}$$

The product of concentration of H^+ and OH^- ions is called the ionic product of water. The value of this constant is 10^{-14} g /l. Thus when the hydrogen ion concentration of an aqueous solution increase, its hydroxyl ion concentration decreases, to maintain the value of the ionic product of water i.e., 10^{-14} g / liter, as a constant.

pH and its Method of Expression

pH: Sorenson (1909) suggested the term pH (Puissance de hydrogen) which means power of hydrogen. pH is the negative logarithm of hydrogen ion activity. pH may also be defined as the logarithm to the base ten of the reciprocal of hydrogen ion concentration. Mathematically,

$$pH = \log_{10} \frac{1}{(H^+)} = \log_{10} (H^+)^{-1} = \log_{10} (H^+)$$

Hence pH is the negative logarithm to the base 10 of its hydrogen ion concentration.

A normal solution of HCl contains 1-g hydrogen per litre, so its pH is $\log 10^0 = 0$ (since $10^0 = 1$)

Since 0.1 N HCl contains 1/10 g of hydrogen, so its pH is $\log_{10} 10^{-1} = \log_{10} 10^{-1} = 1$ (since $10^1 = 10$)

Also 0.01 N HCl contains 1/100 g of hydrogen/litre, so its pH is $\log_{10} 10^{-2} = \log_{10} 10^{-2} = 2$ (since $10^2 = 100$)

At neutrality, the H-ion concentration is 0.0000001 or 1×10^{-7} g of hydrogen/l
Substituting this concentration in the formula,

Table 15.1. The relationship between H⁺ ion concentration pH, pOH, acidity and alkalinity.

PH	H-ion concentration	Acidity (Normality of OH+)	Alkalinity (Normality of OH-)	pOH
0	1×10 ⁰	1.0	0.000000000000001	14
1	1×10 ⁻¹	0.1	0.00000000000001	13
2	1×10 ⁻²	0.01	0.0000000000001	12
3	1×10 ⁻³	0.001	0.0000000001	11
4	1×10 ⁻⁴	0.0001	0.0000000001	10
5	1×10 ⁻⁵	0.00001	0.000000001	9
6	1×10 ⁻⁶	0.000001	0.00000001	8
7	1×10 ⁻⁷	0.0000001	0.0000001	7
8	1×10 ⁻⁸	0.00000001	0.000001	6
9	1×10 ⁻⁹	0.000000001	0.00001	5
10	1×10 ⁻¹⁰	0.0000000001	0.0001	4
11	1×10 ⁻¹¹	0.00000000001	0.001	3
12	1×10 ⁻¹²	0.000000000001	0.01	2
13	1×10 ⁻¹³	0.0000000000001	0.1	1
14	1×10 ⁻¹⁴	0.00000000000001	1.0	0

$$\text{pH} = \log_{10} \left(\frac{1}{0.0000001} \right) = \log_{10} 10000000 = 7 \text{ (Since } 10^7 = 10000000 \text{)}$$

Similarly at pH 6, there is 0.000001 g hydrogen / l

$$\text{pH} = \log_{10} \left(\frac{1}{0.000001} \right) = \log_{10} 1000000 = 6 \text{ (Since } 10^6 = 1000000 \text{)}$$

Thus pH 6 is ten times more acidic than pH 7. In a similar way, pH 5 is hundred times more acidic than pH 7.

pH scale varies from 0 to 14. At pH 7, concentration of H⁺ and OH⁻ ions is equal. If H⁺ ion concentration is 1×10⁻¹, its pH will be 1. In this situation, the concentration of OH⁻ ions will be 1×10⁻¹³. (Since Kw (H⁺) (OH⁻) = 1×10⁻¹⁴)

The relationship between H⁺ ion concentration pH and pOH are presented in Table 15.1.

FACTORS AFFECTING SOIL REACTION

Soil pH results from the interaction of soil minerals, ions in solution, and cation exchange. High pH is caused by the reaction of water and the bases calcium, magnesium and sodium to form hydroxyl ions. Low pH is caused by the percolation of acidic constituents (for example, aluminium released by hydrolysis of the primary minerals) which results in the replacement of exchangeable bases by hydrogen ions. The factors affecting soil pH can be summarized below:

Presence of hydrogen and aluminium ions: Presence of more H-ions than OH⁻ ions makes soil acidic. Al³⁺ ions react with water to liberate H-ions (Hydrolysis)

and thus contribute to soil acidity.

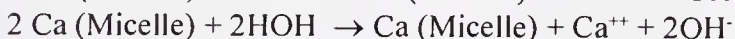
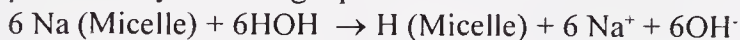


Percentage base saturation: It decreases with high rainfall due to leaching of bases. If percentage base saturation is below 80 soil turns acidic, if between 80 to 90 soil is neutral and when above 90, soil is alkaline in reaction.

Nature of clay: More hydrogen ions are adsorbed and released by clays possessing high CEC (montmorillonite) than by clays with low CEC. For example, if CEC of montmorillonite and kaolinite are 100 and 4 cmol / Kg respectively, then at 80% base saturation, these clays will contain 80 and 3.2 cmol/kg of hydrogen ions. (Solution $80 \times 100/100 = 80$ and $4 \times 80/100 = 3.2$)

Thus, at equal base saturation, montmorillonite dominant solution will contain more hydrogen ions than kaolinite soil solution. Thus, pH of montmorillonitic soil will be less than that of kaolinitic soil. 2:1 clay minerals have a high buffering capacity.

Exchangeable ions: Sodium ions are held less tenaciously than calcium ions. If a soil containing Na^+ and Ca^{++} undergoes hydrolysis, the reactions can be presented by following equations:



From these equations, it is apparent that more OH⁻ ions are released through hydrolysis of Na-micelle than from Ca-micelle. This results in higher pH in soils dominated by sodium as compared to calcium.

Soil pH variations-effect of dilution: Soil water suspension is usually prepared for measurement of soil pH. Dilution and concentration affect the suspension in two opposite ways. Dilution may cause dissociation increasing the number of hydrogen ions, but at the same time lowers the concentration of these ions. On the contrary, concentration causes less dissociation but increases the number of hydrogen ions per unit volume. Actual measurements show that pH of soil suspension increases on dilution and vice versa, but the change is very small. Changes due to dilution and salts range between 0.1 and 0.5 pH unit respectively. 1:2.5, soil : water suspension is commonly used. Soils having pH above 8.5 with high sodium show increase in pH on dilution because of hydrolysis and formation of sodium hydroxide. Thus soil to water ratio affects pH in presence of salts. Since soil reaction varies with the salt content of soil, it is preferred to measure pH in soil suspension in 0.01 M CaCl_2 or 1 N KCl solution, so that fluctuations in pH measurements are avoided. The measurement should be carried out at 25°C or for any change in room temperature following correction is introduced, i.e.

$$0.059(t_R + 273)$$

Where, t_R is the room temperature

METHOD OF DETERMINATION OF SOIL pH

Practical Problems in Measurement of Soil pH

Following factors cause problems in accurate measurements of soil pH:

Clay content: It is not possible to measure the pH of a dry soil. More water may be needed for a dry soil with high clay content than for a dry sandy soil.

Organic Matter: Soil organic matter may absorb substantial quantities of water.

Presence of electrical double layer: It is known that exchangeable ion are loosely held around colloidal surfaces. The surplus negative charge on mineral particle surfaces is balanced by adsorbed exchangeable cations. Thus a zone of weak positive charge develops which attracts anions. The net effect is that the concentration of ions in the bulk solution may differ from that in the immediate vicinity of the particles.

Soluble salt content: As an air dried soil equilibrates with distilled water over 60 minutes, the measured pH value tends to fall as the concentration of the soluble salts increase slightly and more H^+ ions are displaced from the exchange complex.

Microbial activities: CO_2 released from microbial respiration produces carbonic acid.

As a result of these complications, dilute solution of $CaCl_2$ (0.01 M $CaCl_2$) or 1 N KCl is added to the dry soil to reduce variability. This avoids variation in soil pH to a great extent. The following explanation justifies this. Determination of quantities such as pH - pK, pH - $1/2$ pCa and pK - $1/2$ pCa have shown that they remain reasonably constant with increasing concentration of salt up to a certain point. Schofield and his colleagues have found that N/100 $CaCl_2$ solution is convenient for many soils and give results for pH - $1/2$ pCa, for instance, which differ by less than 0.02 units for more precise values obtained with lower salt concentrations.

Lime Potential

Measurement of pH can give variable results due to dilution effect, suspension effect etc. Use of 0.1 M $CaCl_2$ solutions for obtaining stable pH readings is good. However, instead of using single ion activity measurements, Schofield and Taylor (1955) suggested the use of ion activity ratios for determination of pH. If the soil exchange complex is saturated with both H^+ and Ca^{++} ions, by Schofield's ratio law at equilibrium,

$$\frac{(H^+)}{(\sqrt{Ca^{2+}})} = \text{constant}$$

By taking - log, the ratio changes to

$$-\log \frac{(H^+)}{(\sqrt{Ca^{2+}})} = \text{constant}$$

$$-\log (H^+) - [\log(\sqrt{Ca^{2+}})] = \text{constant}$$

$$\text{Or } pH - \frac{1}{2} P_c = \text{constant}$$

This equation is called the *lime potential*. Its value does not depend on the salt content or the soil water ratio. It is considered to be a better index of soil reaction than pH.

Soil pH Measurement

The most widely used method involves measuring pH in a saturated paste or

a dilute soil water suspension with a pH meter using glass electrode. Besides this, indicator methods and use of pH color strips is also common.

Glass electrode method: Glass electrode is combined with a reference electrode (calomel electrode) and e.m.f. is measured. The glass electrodes are made from a thin walled bulb of low melting glass having high electrical conductivity. It is placed in a buffer solution of known pH. Platinum wire acts as a chemically inert electrode, but as a conductor of electrons. The bulb is then inserted in the experimental solution and the difference in potential between, (solution in the bulb) platinum wire and external solution (soil solution outside) is determined by combining with a reference electrode, with the help of a potentiometer. The glass electrode scale of pH of electro motive force is calibrated with two buffer solutions of known pH usually pH 4.0 and 9.0. This is called standardizing the electrodes in the pH meter (Fig. 15.1).

Indicator method: Air- dried soil is placed in a glass tube up to a certain height, followed by an equal height of pure barium sulfate salt. Water is then added equal to six times the volume of soil used. Contents are shaken followed by addition of 7 to 8 drops of a wide range indicator and gently swirled to mix the indicator. pH is found by comparing with a standard color chart for the indicator used.

Use of colour strips: For rapid use in the laboratory, use of paper strips is common. In a soil water suspension (1:2.5 soil water ratio) or the given aqueous solution the paper strips are dipped. The change in the color of the paper strips is compared with those provided along with these strips and corresponding pH is read.

SOIL pH AND NUTRIENT AVAILABILITY

Most crop plants do well in the pH range of 6.5 to 7.5. Thus, soil conditions related to soil pH are more important rather than the number of H or OH ions present in soil. The general relationship between pH and nutrient availability is presented in Fig 15.1.

- The maximum availability of N, P, K, Ca, Mg, S, is in the range of pH 6.5 to 7.5.
- The availability of minor element is more in the acid range. The requirement of minor elements Zn, Fe, Mn, Cu being very small, the quantities of these nutrients available at pH 6.5 to 7.5 is sufficient to meet the requirement of plants.
- Molybdenum becomes more available with increasing soil pH. However it is not deficient under low pH.
- Influence of soil pH on exchangeable calcium and magnesium and on the solubility of aluminium; iron and micronutrients is more important. Under acidic conditions as developed in humid regions because of high rainfall due to leaching of bases, Al, Fe and micronutrients become toxic. They are more soluble at low pH. Below pH 5.5, aluminium begins to leave the structure of silicate clays. High levels of soluble aluminium are injurious to plants. Aluminium toxicity increases water stress during dry period. Calcium and magnesium become deficient due to their leaching.

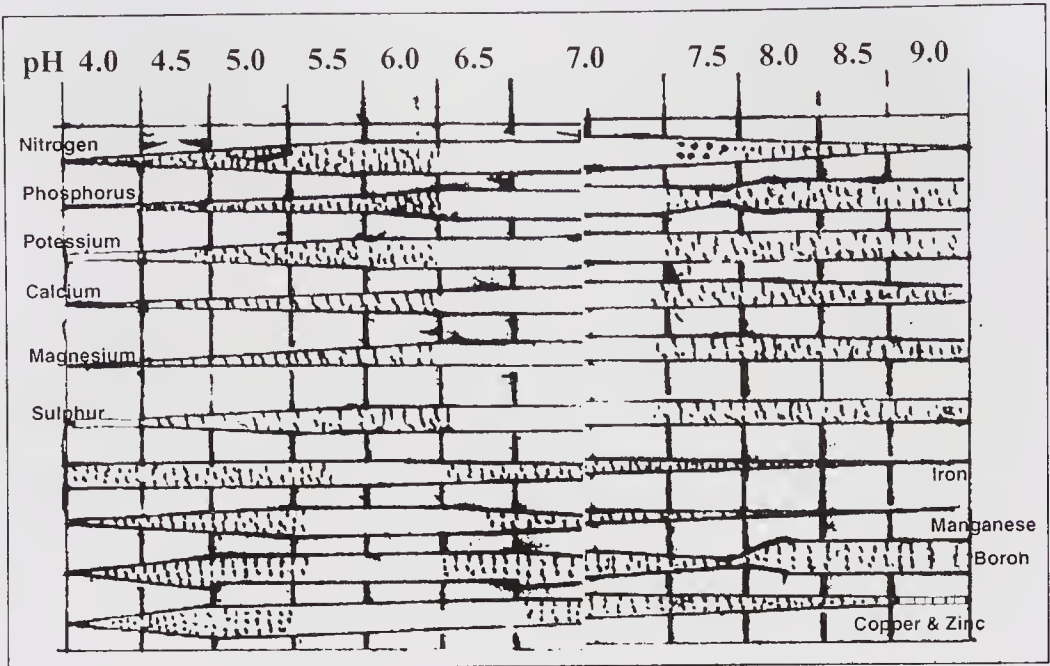


Fig. 15.1. Soil pH and availability of nutrients

Soil pH and Availability of Phosphorus

- This is important in relation to the kind of phosphate ion present with changes in soil pH. At pH 5.5, H_2PO_4^- ion is dominant; HPO_4^{2-} ion becomes dominant as the pH increases up to 7.0 but when pH is more than 7.5, PO_4^{3-} ions are present in excess. H_2PO_4^- and HPO_4^{2-} ions being more important from the point of view of availability of phosphorus, soil pH which yields a mixture of these two forms of phosphorus is preferred.
- At pH values of less than 5.0, soluble phosphates are 'fixed' as complex and insoluble compounds of Fe, Al and Mn.
- At pH values of more than 7.0, complex insoluble calcium phosphates like oxy-apatite $(\text{Ca}_3(\text{PO}_4)_2)_3 \text{CaO}$ and flour-apatite $(\text{Ca}_3(\text{PO}_4)_2)_3 \text{Ca F}_2$ are formed.
- Excess calcium also hinders phosphorus absorption and utilization by plants. Thus at pH between 6 to 7, phosphorus availability is maximum and its fixation is minimum.

SOIL ORGANISMS AND pH

- Bacteria and actinomycetes function better at intermediate and higher pH values that is at pH more than 6.0.
- Fungi works satisfactorily at all pH ranges. Thus, they can function better at low pH values (pH less than 6) while they face a strong competition at higher pH values with bacteria and actinomycetes. However, the bacteria responsible for oxidation of sulfur to sulfuric acid also functions satisfactorily at all pH values. Activities of these bacteria makes application of sulfur effective to develop acidic conditions.

- Processes of nitrification take place effectively at pH above 5.5. However, ammonification, amination proceed as fungi affects their enzymic transfers, but these processes are definitely curtailed at lower pH values. Thus pH between 6.5 to 7.5 is satisfactory for biological regime and availability of plant nutrients including phosphorus.

BUFFERING

Buffering refers to resistance to a change in pH. Buffering in soils is their resistance against any change in the concentration of hydrogen or other cation in the soil solution. For example, if 1 ml of 0.1 N HCl is added to one litre of distilled water of pH 7.0, the resulting solution will have a pH 6.0.

[Since $\text{pH} = \log_{10} 1/\text{H}^+ = \log_{10}^{1/10} = \log_{10}^{10} = 1$ (since $10^1 = 10$) Thus pH will be lowered by 1]

Such lowering of pH will not result with same water containing a little amount of soil. The presence of soil in water resists a change in pH to the desired level upon addition of acid of known strength.

Buffering Action

The power to resist a change in pH is due to buffering action. A buffer solution is one that contains reserve acidity and alkalinity and resists change either by small additions of acids or alkalies. A solution containing a weak acid and salt of it with a strong base, for example acetic acid and sodium acetate or a weak base and salt of it with a strong acid for example, ammonium hydroxide and ammonium chloride shows this property. The mechanism of buffering action can be explained as follows:

- Acetic acid is a weak acid and there will be less hydrogen ions in solution, because most of it remains in the molecular form, only a part of it is ionized. Sodium acetate dissociates into Na^+ and CH_3COO^- ions. Thus the solution contains CH_3COO^- , H^+ , Na^+ and OH^- ions. Now, if a strong acid like HCl is added, it dissociates into H^+ and Cl^- ions. The H^+ ions combine with acetate ions forming acetic acid which being a weak acid, there is no change in pH or only a slight change occurs. In a similar way when a strong base is added to it, the OH^- ions so produced neutralize H^+ ions without any change in pH.

Mechanism of buffering action may be presented through equation as follows:

- Acetic acid and its salt with a strong base
 - $\text{CH}_3\text{COOH} \rightarrow \text{CH}_3\text{COO}^- + \text{H}^+$
 - $\text{CH}_3\text{COONa} \rightarrow \text{CH}_3\text{COO}^- + \text{Na}^+$ (excess of Na^+ and CH_3COO^- ions)

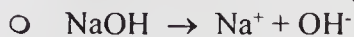
On addition of a strong acid

- $\text{HCl} \rightarrow \text{H}^+ + \text{Cl}^-$

H^+ combines with CH_3COO^- ions to form acetic acid (weak acid). Thus there is no change in pH.

- Ammonium hydroxide and its salt with a strong acid
 - $\text{NH}_4\text{OH} \rightarrow \text{NH}_4^+ + \text{OH}^-$
 - $\text{NH}_4\text{Cl} \rightarrow \text{NH}_4^+ + \text{Cl}^-$

On addition of a strong alkali



OH^- combines with NH_4^+ to form NH_4OH (weak base). Thus there is no change in pH.

BUFFERING IN SOILS

In soils, the clay and humus acts as a buffer system. Soil exchange complex has reserve and active acidity and there exists an equilibrium between these two. If the active acidity is neutralized by the addition of lime, the reserve acidity will release exchangeable H^+ ions into the soil solution to maintain the equilibrium and no change in soil reaction occurs. The buffering capacity is greater in clay soils than in sandy soils. The colloidal complex behaves in a way similar to a mixture of weak acids and their salts and acts as a buffer. In soil, buffering action may be due to one or several of the following buffering agents:

- Carbonates, bicarbonates and phosphates present in soil.
- Colloidal complex with associated cations acts as a buffering agent.
- Organic acids are being continuously formed in soil as a result of microbial activity. Organic acids are weak acids.
- H^+ ions are released from the soil exchange complex and thus provide reserve acidity. As soon as H^+ ions in soil solution are neutralized by basic substances, more of H^+ ions are released from soil exchange complex, thereby not allowing a rapid change in pH.

BUFFERING CAPACITY OF SOILS AND BUFFERING CURVES

Soils are a mixture of acidoids (acid producing substances) and basoids (base forming materials). The soils exhibiting both acidic and basic properties at a time because of its constituents are called amphoteric soils. The basis of buffering capacity of soil lies in the adsorbed cations of the soil complex including hydrogen and aluminium ions. There is equilibrium between adsorbed hydrogen and aluminium ions and hydrogen ions of the soil solution. This can be represented as below:

Adsorbed H^+ and Al^{3+}	$\leftrightarrow$ Soil solution containing H^+ and Al^{3+} ions
(Reserve acidity)	(Active acidity)

Buffering Curves

Buffering curves for soils can be prepared by treating soil with acids or alkalis of known strength and comparing with curves obtained by water without soil (Fig 15.2). Following procedure may be followed to prepare such curves:

Weigh 10 g of soil and add varying amounts of 0.01N HCl and 0.01N NaOH. (0, 20, 40, 60, 80, 100, 120 & 140 ml of 0.01N HCl & 0.01N NaOH which gives 0.2, 0.4, 0.6, 0.8, 1.0, 1.2 & 1.4 me of HCl and NaOH respectively, 1 ml of normal solution = 1 me. Therefore 20 ml of 0.01 N solution = 0.2 me. And so on). Allow it to stand for 24 hours to attain the equilibrium. Record pH and plot as indicated in Fig 15.2. A blank is plotted with water, without soils. Changes in pH values are

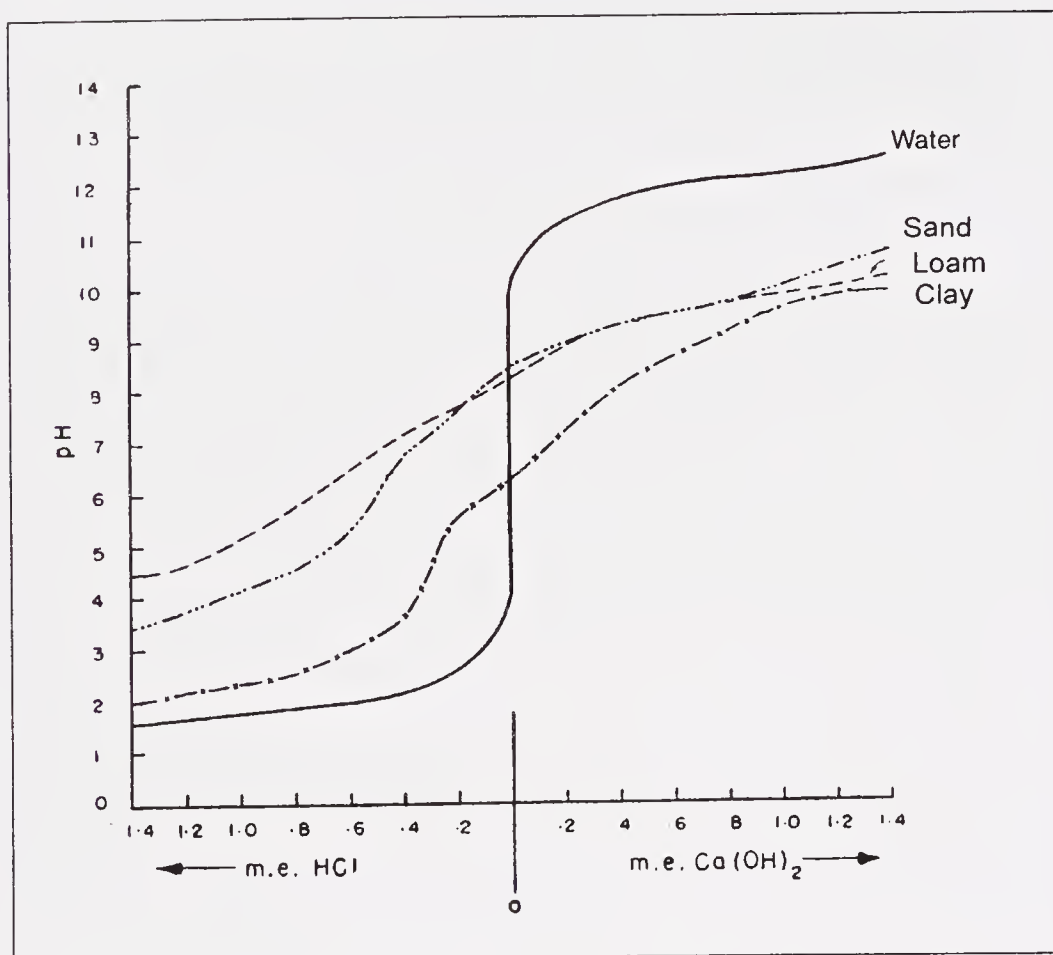


Fig 15.2. Generalized buffering curves of water and sand, loam and clay soils

recorded. The divergence of an individual buffering curve from 'blank' curve gives a measure of interaction between the soil and the acid or alkali. The greater the buffering capacity, there is tendency for curve to be horizontal. Thus, these curves are more horizontal for fine textured soils and those rich in high exchange capacity clays as compared to coarse textured soils and low in exchange capacity clay.

FACTORS AFFECTING BUFFERING CAPACITY OF SOILS

Buffering capacity of soil depends on:

- Texture of the soil, kinds and amount of colloidal material present.
- In general, the fine textured soils possess greater buffering than coarse textured soils, this is because of greater surface area and greater exchange capacity of finer textured soils than coarse textured soils.
- If colloidal material has high exchange capacity, it has greater buffering capacity. Therefore a soil high in clay or organic matter require larger amount of amendment for affecting a certain change in pH. For example, to raise pH of an acid soil to a desired level more lime will be required in a heavy textured soil (or clay) than in a coarse textured soil. (Loamy or sandy). This can be

explained as follows:

When the buffering capacity of a soil is high for example in soils rich in clay and organic matter, larger quantities of nutrients added to the soil will be retained.

IMPORTANCE OF BUFFERING

Buffering of soil help in

- Stabilization of soil pH
- Calculations of amount of amendment necessary to affect a certain change in soil reaction.

pH range of 6.5 to 7.5 is considered better basically because of two main reasons (a) The availability of nutrients to plants is satisfactorily met in this pH range. (b) It is suitable for activities of soil micro-organisms responsible for transformation of nutrients in their available forms. Thus sudden fluctuations below or above this pH range are not desirable. It is because of buffering capacity of soils that such fluctuations or changes in pH do not occur.

Knowledge of buffering capacity of soils helps to facilitate the amount of amendment like lime or gypsum, which should be applied for affecting the desired change in pH.

References and Suggested Readings

- Biswas, T.D. and Mukherjee, S.K. (1989). *Textbook of Soil Science*. Tata McGraw Hill Publishing Company Ltd., New Delhi.
- Cresser, M. Killham, K. and Edwards, T. (1993). *Soil Chemistry and its Applications*. Cambridge Environmental Chemistry Series 5, Cambridge University Press, London.
- Schofield and Taylor (1955). *Principles of Soil Chemistry*, pp. 271–277. Kim H Tan Marcel Dekker, Inc. New York.
- Tisdale, S.L., Nelson, W.L., Beaton, J.D. and Havlin, J.L. (1997). *Soil Fertility and Fertilizers*. MacMillan Publishing Co. New York, USA.

QUESTIONS

Q. 1. Fill in the blanks

- i) The product of concentration of H^+ and OH^- is called the _____.
- ii) The pH of 0.1 N HCl solution is _____.
- iii) If H^+ ion concentration is 1×10^{-5} , its pH will be _____.
- iv) Since soil reactions varies with the salt content of soil, it is preferred to measure pH of soil suspension in _____ solution.
- v) If percentage base saturation falls below 80, soils turn _____.
- vi) Soils having pH above 8.5 with high sodium, show an increase pH on dilution because of formation of _____.
- vii) At pH values of less than 5.0, soluble phosphates are fixed as insoluble compounds of _____.
- viii) If 1 ml of 0.01 N HCl added to 1 litre of distilled water, the resulting solution will have a pH _____.

Answers

(i) Ionic product of water (ii) One (iii) Five (iv) 0.01 M CaCl_2 or 1N KCl (v) Acidic (vi) Sodium hydroxide (vii) Fe, Al and Mn (viii) Five.

Q. 2. Choose the correct answer

- i) 0.01 N HCl contains 1/100 g / 1/10 g of hydrogen per litre
- ii) The pH of a solution containing 0.001 N HCl is 3/2
- iii) Below a pH of 5.5, aluminium / calcium begins to leave the structure of silicate clays
- iv) Molybdenum / manganese becomes more available with increasing soil pH
- v) At pH 5.5, H_2PO_4^- / PO_4^{3-} ion is dominant
- vi) At equal base saturation, montmorillonite / kaolinite dominant solution will contain more H-ions

Answers

(i) 1/100 gm (ii) 3 (iii) aluminium (iv) molybdenum (v) H_2PO_4^- (vi) montmorillonite

Q. 3. Define the following

(i) pH (ii) Ionisation constant (K_w) (iii) Buffering

Q.4. Differentiate between the following:

- i) Hydrolysis of a Na^+ dominant soil and a Ca^{++} dominant soil
- ii) Buffering curves of a clay soil and a sandy loam soil

Q. 5. Write short notes on the following

(i) Effect of dilution on soil pH in a soil water suspension (ii) Lime potential (iii) Amphoteric nature of soil (iv) Importance of buffering (v) Practical problems in measurement of soil pH

Q. 6. Comment on the following

- i) When the hydrogen ion concentration of an aqueous solution increases, hydroxyl ion concentration decreases.
- ii) A normal solution of HCl has a pH 'zero'.
- iii) pH 5 is hundred times more acidic than pH 7.
- iv) There is a change in soil pH under natural conditions.
- v) At equal base saturation, the pH of a montmorillonite dominant soil is less than a kaolinite dominant soil.
- vi) Soil to water ratio affects pH in presence of salts.
- vii) Addition of 0.01 M CaCl_2 to a dry soil reduces variability in measurement of soil pH.
- viii) pH between 6 to 7 is ideal from the point of view of availability of phosphorus
- ix) In soils, clay and humus acts as a buffer system.
- x) Buffering curves are more horizontal for soils rich in exchange capacity.
- xi) A soil high in clay or organic matter will require a larger amount of amendment for affecting a certain change in pH.
- xii) Increasing the dilution of the soil from saturation to 1:10 soil water will

generally increase the measured pH.

xiii) Al^{3+} ions contribute to soil acidity.

xiv) pH is the negative logarithm to the base 10 of its hydrogen ion concentration.

Q.7. Answer the following in brief

- i) Derive the expression $-\log_{10} (\text{H}^+)$
- ii) How does aluminium ions cause acidity
- iii) Montmorillonite will release or adsorb more hydrogen ions than kaolinite. Illustrate with example
- iv) How does the presence of electrical double layer on clay cause pH variations
- v) What is the influence of pH on the availability of Ca, Mg, Al, Fe and micronutrients
- vi) How does pH affect availability of phosphorus
- vii) Explain the mechanism of buffering action with two examples
- viii) Enlist buffering agents in soil

Q. 8. Answer the following in detail

- i) Explain the method for determination of soil pH
- ii) Explain factors affecting soil reaction

Q.9. Give diagrammatic view of the following

- i) Measurement of pH by glass electrode method
- ii) Relation between pH and nutrient availability
- iii) Hypothetical buffering curves of soils of three different textural classes (sandy loam, loam and clay loam).



Origin, Reclamation and Management of Saline and Alkali Soils and Quality of Irrigation Water

IT has been reported that all over the world 45,000 million hectares are degraded in some way or other (Mabbutt 1984), thus threatening the sustainability of agricultural production. In India, the extent of salt affected soils has increased continuously. It was reported 7 million hectares (Abrol and Bhumbra, 1971) to 10 million hectares (Bhargava, 1989). According to Vohra (1987) about 13 million hectare, which are otherwise not being put to productive uses, are salt affected. Soil salinity is one of the major problems restricting crop production in the arid and semi-arid regions of the world, particularly under irrigated conditions. Leaching of salts is the ultimate necessity to make effective use of such soils. During leaching of these soils release of soil nutrients and their loss to the ground water is very usual. For example, the availability of nitrogen is reduced due to its slow mineralization. Crops respond to application of NPK fertilizers under these situations. Plants growth is adversely affected as water availability is reduced because of osmotic effects due to excessive salts. High absorption of individual ion may prove toxic to the plants and/or may retard the absorption of water and other essential plant nutrients.

In arid and semi-arid parts of our country, the underground water, largely brackish in nature, is an important source of irrigation. Use of such water causes deleterious effect on physico-chemical properties of soils and result in their sodification. Water being a scarce commodity in these areas, it becomes necessary to make use of the available poor quality ground water by adopting suitable technology. The extent and placement of Indian soils in different types of salt-affected categories are shown in Tables 16.1 and 16.2.

CHARACTERISTICS OF SALT AFFECTED SOILS

Units of Expression for Salinity and Alkalinity

Salinity is measured in terms of electrical conductivity (EC), which is the ability of the salt solution to conduct electricity. It is expressed in terms of decisimens per metre (dsm^{-1}). Sodium is involved in alkalinity. It is expressed in terms of exchangeable sodium percentage (ESP), that is the degree of saturation of exchange complex with sodium and sodium adsorption ratio (SAR), which is a comparative ratio of Ca^{++} , Mg^{++} and Na^{++} .

Table 16.1. Broad groups of salt affected soils in India

Group	States	Approximate Area (million ha)
Coastal salt-affected soils		
• arid regions	Gujarat, West Bengal,	0.714
• humid region	Orissa, Andhra Pradesh,	1.394
• acid salt-affected	Tamil Nadu, Kerala	0.016
Salt-affected soils of the medium and deep black soil regions	Karnataka, Madhya Pradesh, Andhra Pradesh, Maharashtra	1.420
Salt-affected soils of the arid and semi-arid regions	Gujarat, Rajasthan, Punjab, Haryana and Uttar Pradesh	1.000
Alkali soils of the Indo-Gangetic Plains	Haryana, Punjab, Uttar Pradesh, Bihar, Rajasthan, Madhya Pradesh	2.500
Total		7.044

Source: Abrol and Bhumbla, 1971

ESP =
$$\frac{\text{Exchangeable sodium (cmol/kg)}}{\text{Cation exchange capacity (cmol/kg)}} \times 100$$

Na⁺

SAR =
$$\sqrt{\frac{\text{Ca}^{++} + \text{Mg}^{++}}{2}}$$

Table 16.2. Placement of salt affected soils in soil taxonomy

Order	Sub-order	Great group
Alfisols	Aqualfs, Udalfs, Ustalfs	Natraqualfs, Natrudalfs, Natrustalfs
Aridisols	Argids, Calcids	Natrargids, Petroargids, Haplocalcids
	Cambids	Aquicambids, Haplocambids, Petrocambids
	Cryids	Salicryids, Agricryids,
	Durids	Natridurids
	Gypsid	Haplogypsid, Natrigypsid
	Salids	Aquisalids, Haplosalids
Entisols	Aquepts	Endoaquepts, Psammaquepts, Torriarents
Inceptisols	Aquepts	Halaquepts, Sulfaquepts, Vermaquepts,
	Xerepts	Calcixerepts
Mollisols	Albolls	Natralbolls
	Aquolls	Natraquolls, Duraquolls
	Cryolls	Natricryolls
	Udolls	Natrudolls
	Ustolls	Natrustolls, Calciustolls, Durustolls, Haplustolls
	Xerolls	Netrikerolls

Source: Velayutham and Bhattacharya 2000

Where Na^+ , Ca^{++} and Mg^{++} are concentration of these cations in millimoles per litre (m mole/l). SAR also characterizes quality of irrigation water. SAR has a good correlation to the exchangeable sodium percentage (ESP) and is much easier to calculate exactly.

Critical Values of EC

The selection of the critical value for EC of 4 is based on the expected salt damage to crops. At this value, the yield of many crops is restricted.

Salinity effect mostly negligible	Yield of very sensitive crops may be restricted	Yield of many crops restricted	Only tolerant crop yield satisfactory	Yield of a few tolerant crops are satisfactory
0	2	4	8	16

ECe (Electrical conductivity in ds/m at 25° C)

The effect of degree of salinity as expressed in ECe values, on yield of crops according to the US Salinity laboratory (Richards, 1954).

The US Salinity laboratory has from history and experience assigned, ESP 15 as a boundary unit to distinguish non-alkali from alkali soils.

Characteristics of Saline Soils

Saline soils contain neutral soluble salts of chlorides and sulfates of sodium, calcium and magnesium. The electrical conductivity of saturated extract of the soil is more than 4 decisiemens per metre (ds/m) at 25°C, ESP is less than 15 (SAR < 13) and pH less than 8.5. Because of the presence of excess salts and low amounts of Na^+ in the exchange position, these soils are in a flocculated state, their permeability is higher than alkali or saline alkali soils. Their physical condition is good and water can pass through them. These soils have a white crust of salts on their surface. Salinization refers to the accumulation of neutral soluble salts in soils. ES, ESP and ph values of saline, saline alkali and alkali soils have been inciated in Table 16.3.

Characteristics of Saline Alkali Soils

These soils have both soluble salts and exchangeable sodium. As long as excess salts are present, the soil is flocculated and pH is less than 8.5. When such soils are leached, their soluble salts content decreases, the soil reaction becomes strongly alkaline because of hydrolysis of exchangeable sodium. The soils are in a transitional stage, that is, they may be converted into saline by removal of their sodium and into alkali if sodium content is further increased and physical condition is deteriorated. The properties of these soils include characteristics of sodium and such soils may still be considered better than alkali soils. The EC of saturated extract is more than 4 ds/m, ESP is more than 15 (SAR > 13) and pH is usually less than 8.5. The pH is variable depending on the relative amounts of exchangeable sodium and soluble salts. When soils are dominated by exchangeable sodium, the pH will be more than 8.5 and when soluble salts dominate soils, the pH will be less than 8.5.

Table 16.3. Electrical conductivity, exchangeable sodium percentage and pH values of saline, saline alkali and alkali soils

	EC	ESP	pH
Saline	>4	<15	<8.5
Saline alkali	>4	>15	<8.5 (usually
Alkali	<4	>15	>8.5

Characteristics of Alkali Soils

Most of the Na⁺ is in exchangeable form and very small amounts of soluble salts are present in the soil solution. Because of lower contents of soluble salts, the EC of saturated extract is less than 4 ds/m. ESP is more than 15 (SAR>13) and pH more than 8.5. Such soils are not in a good physical condition. The surface of these soils is sometimes black due to the dispersion of organic matter and humus. Such soils, if, ploughed when wet, turns in to slick furrow slice. Such spots are called slick spots. The process whereby a normal soil is converted into an alkali soil is known as alkalization. Any soil having pH greater than 7.0 are called alkaline soil.

Degraded Alkali Soils

In areas of excess rainfall due to absence of calcium and magnesium, part of the exchangeable sodium (in alkali soils) is replaced by hydrogen. The hydrolysis of sodium soils results in the production of sodium hydroxide and then hydrogen soil develops. This may be shown as follows:

- i) $\text{Na-soil} + \text{H}_2\text{O} \rightleftharpoons \text{NaOH} + \text{H-soil}$
- ii) $2 \text{NaOH} + \text{CO}_2 \rightleftharpoons \text{Na}_2\text{CO}_3 + \text{H}_2\text{O}$
- iii) Hydrogen soil so formed is degraded further in to silicic acid and forms sesquioxides. Sodium carbonate so formed dissolves humus, which may be deposited in the lower layers. Such soils are called degraded alkali soils. Raising their pH through the application of lime can reclaim these soils. Use of fertilizers to meet nutrient need of plants growing in such soils is beneficial.

CAUSES OF FORMATION OF SALINE AND ALKALI SOILS

Weathering of Rocks and Minerals

Chemical weathering results in the release of neutral soluble salts including those of Ca⁺⁺, Mg⁺⁺ and Na⁺. These salts move downwards and get deposited in the lower layer of soil with a little amount of rainfall but again move upward due to high temperature. When water evaporates, these salts accumulate on the surface of the soil as white crust.

Hydrolysis of Sodium Saturated Soil Complex

Sometimes soluble salts in the process of leaching of calcium ions are replaced by sodium ions. Soil micelle is then saturated with sodium resulting in the formation of sodium carbonate. Sodium carbonate so formed undergoes hydrolysis

to form sodium hydroxide, which dissociates to increase concentration of hydroxyl ions in soil solution. The reactions may be explained as follows

- $\text{Ca(micelle)} + \text{Na}^+ + \text{H}_2\text{CO}_3 \rightarrow \text{Na(micelle)} + \text{H}^+ + \text{Na}_2\text{CO}_3$
- $\text{Na}_2\text{CO}_3 + 2\text{H.OH} \rightarrow 2 \text{NaOH} + \text{H}_2\text{CO}_3$
- $2 \text{NaOH} \rightarrow 2\text{Na}^+ + \text{OH}^-$

Formation of OH^- ions results in an increase in pH.

Salty Underground Water

The ground water of arid region contains considerable quantities of soluble salts. These salts move upward with water and get deposited when water evaporates.

Arid and Semi-Arid Climate

Poor rainfall and high temperature of arid and semi-arid regions are very favourable conditions leading to formation of saline and alkali soils. The low rainfall in these regions is not sufficient to leach down the soluble weathered products and hence the salts accumulate in the soil. In summary, salts move up with water due to evaporation. As water is evaporated in the atmosphere, the salts are left behind in the soil.

Quality of Irrigation Water

If water available for irrigation contains excessive amounts of Ca^{++} , Mg^{++} , Na^+ , Cl^- , $\text{SO}_4^{=}$, HCO_3^- , $\text{CO}_3^{=}$, $\text{BO}_3^{=}$ and NO_3^- , their continuous application is reflected on the quality of soil. Water available in arid region usually contains excess amounts of these salts. Besides this, (a) a rise in the ground water level due to excessive application of water (b) poor drainage which prevents leaching of salts and (c) erratic use of irrigation water, i.e. flooding at one time followed by drought so that salts may remain on the surface of soil leading to the development of saline and alkali soils.

Use of Basic Fertilizers

Use of basic fertilizers like sodium nitrate (NaNO_3), basic slag may develop soil alkalinity (see fate of nitrogenous fertilizers Chapter 18).

EFFECT OF SALINITY AND ALKALINITY ON THE GROWTH OF CROPS

- High salt concentration increases the forces that hold water in the soil and require plant roots to expend more energy to extract water from the soil.
- Presence of excessive quantities of salts including sodium result in an increase in osmotic pressure of soil solution (osmotic effect). Such soil solution when comes in contact with plant cell, forces flow of water from the cells into the more concentrated soil solution. This results in collapse of plant cell or root hair. (Flow of water and nutrient takes place from lower concentration towards higher concentration.)
- Plant roots have to exert more to extract water and nutrients due to presence of more salts in soil solution. Dilution of salty soil solution may protect plant

from adverse effect of salts, thus such soils should be kept moist.

- Usually plant tolerances to salts increase with their maturity. Soil salts do not affect most plants in their mature stage. Alkali soils adversely affect plant growth in many ways:
 - Such soils are in a poor physical condition. The presence of high amount of sodium (Na^+ ions) keeps the soil particles suspended. Upon drying, the crust formation develops at the surface. It decreases soil porosity and inhibits aeration.
 - These soils contain excessive amounts of boron (as borate BO_3^- ion), bicarbonates (as HCO_3^- ions) and sodium (as Na^+ ion).
 - Active sodium ions adversely affect plant nutrition and metabolism. It adversely affects uptake of Ca^{++} and Mg^{++} by plants.
 - Due to high pH under these conditions, availability of phosphorus and micronutrients becomes low, the soils encounter Fe, Cu, Zn and Mn deficiencies.
 - Plant suffers oxygen deficiency as soil structure is adversely affected due to dominance of sodium.

MANAGEMENT AND RECLAMATION OF SALINE AND ALKALI SOILS

Problems of Salt Affected Soils

Salt affected soils (saline and alkali soils) are usually soils of arid or semi-arid regions. This is because of (i) low rainfall, (ii) high evaporation due to high temperature, (iii) restricted drainage leading to high water table and (iv) low permeability of soil due to presence of hard layers (clay pan or caliche layer due to silica hard pan). These salts are mostly NaCl , Na_2SO_4 , CaCO_3 and MgCO_3 . The addition of salts to the soil saturates the exchange complex of soil with sodium.

Limitations in Managing Salt Content of Soils

There are certain practical limitations in managing salt content of such soil. These may be identified as follows:

- The distribution and amount of salt in the field changes frequently, thus sampling after each irrigation is not very practicable.
- As samples are dried in laboratory, rewetted and then stirred. The undried sample with its much lower and fluctuating water content may present a different picture of salt content than in the field.
- Lag time from sampling to the final data usually takes several days. Thus, a field method needs to be developed.

How to Proceed for Reclamation of Salt Affected Soils

Before proceeding for reclamation of such soils, following points should be considered and available information should be collected.

- Nature and extent of salinity
- Quality of irrigation water with respect to sodium, boron and bicarbonate and its salt content
- Drainage conditions
- Nature and distribution of salts in the root zone

- Calcium carbonate content of soil. This is important because saline soils may be of two-type, (i) Those containing reserve CaCO_3 , (ii) Those without CaCO_3 reserves. The reclamation of these soils differs. Those containing CaCO_3 reserves are not damaged by sodium because when sodium salts are removed by flooding, calcium is replaced from CaCO_3 reserves. The soils without CaCO_3 reserves would turn alkali since soil solution rich in sodium would increase exchangeable sodium in soil and a little amount of calcium present in soil is also lost through leaching. Such soils should be first enriched with calcium (preferably through $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) in their exchange complex prior to flooding for removal of excess salts.

Steps for Reclamation of Salt Affected Soils

Based on the above point considered for reclamation of saline and alkali soils, the general steps to reclaim salt affected soils are as follows:

- *Drainage*: If drainage is not adequate, installation of drainage system through construction of ditches or pipelines may be done as feasible.
- *Exchangeable sodium*: Use suitable chemical amendment to replace sodium. It depends on soil texture, clay, and quantity of irrigation water.
- *Leaching*: Replaced sodium must be leached below the root zone. The quantity of water required to remove salts from the soil depends on the depth of salts to be removed, the method of leaching and boron content of soil. Since boron is strongly adsorbed by some soil constituents its leaching may require three times more water than is needed to remove other soluble salts to the same extent (Fig. 16.1).

Reclamation of Saline Soil

Leaching: The main objective in reclamation of these soils is to leach the salts below the root zone. Hence, drainage system should be installed, if necessary. This is achieved by flooding and ensuring that water is drained away to lower depths in soil. To make it effective, bunds are raised around plots prepared according to their textural classes and water is applied depending on their water requirement to leach salts. Water needed to leach salts varies according to soil texture. The heavy soil need more water than sandy or light soils.

Application of Gypsum: If saline soil contain a little amount of sodium, application of gypsum is necessary to displace sodium. This is followed by leaching.

Artificial drainage and deep ploughing: In saline soils, with high water table, artificial drainage should be practiced. If there is any hard pan in the sub soil layer, that may prevent downward movement of water, deep plowing or chiseling should be done to break such layers and open the soil for free downward movement of water.

Use of mulches: In areas where water resources are limited, application of surface organic mulch slows surface evaporation, salt movement by evaporative water is decreased and net downward movement of salt is increased.

Reclamation of Alkali (Sodic) Soil

Reclamation of sodic soil involves two stages. First, the replacement of sodium



Fig. 16.1. Crop production in saline sodic soil at Agricultural Research Station, Vallabhnagar (1982–87) Maharana Pratap University of Agriculture and Technology, Udaipur (Courtesy Dr. F. Karan and Dr. F.M. Qureshi).

A) Untreated saline sodic soil

B) Treated saline sodic soil with crops-mustard (T-59), Barley (BL-2), Wheat (Kharchia)

Treatment: The recommended reclamation technology for saline sodic soil (Sodic calciorthisds) of semi-arid region of Rajasthan is as follows :

Application of Gypsum (@ $\frac{1}{2}$ gypsum requirement) 10 tonnes/h + farmyard @ 10 tonnes/h + Sand @ 10-20 tonnes/h.

1. The treatment is carried out with the onset of monsoon.
2. The farm operations include levelling, bunding, ploughing, ponding and leaching of rain water.
3. Ploughing the field again when in condition.
4. Repeating the process of ponding, leaching and ploughing the field when in condition three times during the rainy season.
5. Final field preparation followed by sowing of resistant crops in the coming rainy season.

by another cation and second, the leaching of salts out of the root zone. Calcium is used to replace sodium in sodic soils. This may be done through gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). Leaching with low salt irrigation is also effective in removing exchangeable sodium. Leaching water contains enough cations to replace sodium. A high salt content in water keeps soils flocculated. However, without gypsum more water may be required to remove the same amount of sodium.

Leaching Requirement

There is a danger of salt build up when irrigating the soil to leach soluble salts. Thus salt balance should be taken into account. Salt balance relates to the amount of salt brought into the soil to the amount of salt leached out of the soil. The additional water used for leaching is called the leaching requirement. (Bernstein and Francois, 1973).

$$LR = \frac{EC_{iw}}{EC_{dw}}$$

Where EC_{iw} is the electrical conductivity of irrigation water

EC_{dw} is the electrical conductivity of saturation extract of saline soil, which exhibited 50% decrease in yield.

If the increase in salinity in irrigation water over the years, the value of LR becomes larger. The irrigation water be managed in such a way that the major needs of crops are supplied at the minimum salinity level of the irrigation water.

Gypsum Requirement

The gypsum requirement (GR) is the calculated amount of gypsum necessary to add to reclaim the soil. It is the amount of gypsum required to be added to a sodic soil to lower its ESP (Exchangeable Sodium percentage) to a desired level. Gypsum requirement may be calculated as me of Ca^{2+} per 100g soil and expressed as tons of gypsum per hectare. An Exchangeable Sodium Percentage (ESP) of 10 and below is considered safe for maintaining optimum conditions, replacement of sodium to this level may be practiced. Gypsum requirement is determined as:

$$\text{Gypsum requirement in m.e. of } Ca^{2+}/100 \text{ g soil} = \frac{\text{ESP (initial)} - \text{ESP (final)} \times \text{CEC}}{100}$$

Where ESP (Initial) : ESP of soil before application of amendments

ESP (final) : ESP of soil after bringing it to a desired level of ESP say, 10

CEC : Cation exchange capacity in Cmol/kg of soil.

For example, the gypsum requirement of a soil having initial ESP 40, final ESP 10 and CEC 25 will be

$$\text{m.e. of } Ca^{2+}/100 \text{ g soil} = \frac{(40-10) \times 25}{100} = 7.5$$

Since one hectare of soil to a depth of 15-cm weighs approximately 2×10^6 kg and 1 me of replaceable gypsum as $CaSO_4 \cdot 2H_2O$ equal 860 ppm of amendment, the theoretical amount of gypsum required per hectare will be:

$$\text{Gypsum (kg/ha)} = \frac{860 \times 2 \times 10^6}{10^6} \times \frac{7.5}{1} = 12.90 \text{ tonnes}$$

Knowing the amount of gypsum required in tonne per hectare, the equivalent quantities of other chemical amendments can be calculated. Rate of gypsum application for its effective application depends on several factors like the purity of material, texture, surface area (fineness, generally gypsum of about 2mm sieve particle size have been used for reclamation of alkali soils); type of clay minerals, organic matter etc. To compensate for these factors, the US Salinity Laboratory Staff recommended that the gypsum requirement obtained by calculation may be multiplied by 1.25 to obtain the desired level of sodium replacement. Application of gypsum at the rate of 50% GR and mixing the gypsum up to 10 cm depth can

be adopted for greater economy and efficiency of reclamation. The amount of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and sulfur required to ameliorate the sodic soils on the basis of exchangeable sodium is given in Table 16.2.

Use of Chemical Amendments

Chemicals, which are added to soil to furnish soluble calcium and replace exchangeable sodium, are called chemical amendments.

Gypsum

Gypsum is used to exchange sodium and remove bicarbonate from the soil solution. Gypsum should be thoroughly mixed in the soil and there should be sufficient moisture for its quick reaction. A heavy irrigation helps in lowering the concentration of soluble carbonate and sulfates in the topsoil and improves the effectiveness of gypsum. Therefore, gypsum may be broadcast evenly when the soil moisture is optimum for mixing in to soil. The action of gypsum may be shown through following reactions.

- $2\text{NaHCO}_3 + \text{CaSO}_4 \rightarrow \text{CaCO}_3 + \text{Na}_2\text{SO}_4 \downarrow + \text{CO}_2$
- $\text{Na}_2\text{CO}_3 + \text{CaSO}_4 \rightarrow \text{CaCO}_3 + \text{Na}_2\text{SO}_4 \downarrow$
(soluble in water)
- $\text{Na}^+(\text{micelle}) + \text{CaSO}_4 \rightarrow \text{Ca}(\text{micelle}) + \text{Na}_2\text{SO}_4 \downarrow$

This should be followed by application of water to leach salts.

Rate of gypsum application depends on soil pH and the amount of exchangeable sodium present on the soil exchange complex. Gypsum is suitable for saline and alkali soils having pH up to 9.0.

Sulphur

Elemental sulfur or sulfuric acids are effective on alkali soils, which contain sodium or calcium carbonates. Powdered sulfur is more effective, as shown in the following reactions:

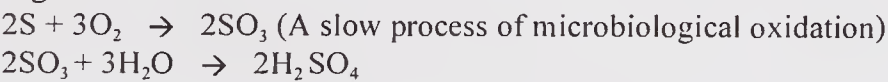


Table 16.4. Amounts of amendments required to reclaim sodic soils on the basis of exchangeable sodium

Exchangeable sodium (me/100 g soil)	Gypsum (tonnes/ha)	Sulfur (tonnes/ha)
1	2.12	0.40
2	4.25	0.80
3	6.50	1.20
4	8.62	1.60
5	10.75	2.00
6	12.87	2.40
7	15.00	2.80
8	17.12	3.20
9	19.37	3.60
10	21.50	4.00

- The hydrogen ions of sulfuric acid can replace sodium ions on the soil cation exchange sites. Na⁺ ions further react with gypsum as follows: (when Ca⁺⁺ source is there in the soil)
 $2\text{Na}^+(\text{micelle}) + \text{CaSO}_4 \rightarrow \text{Ca}(\text{micelle}) + \text{Na}_2\text{SO}_4$
Na₂SO₄ so formed is a mild neutral salt and is leachable.
 - If the soil contains lime;
 $\text{H}_2\text{SO}_4 + \text{CaCO}_3 + \text{H}_2\text{O} \rightarrow \text{CaSO}_4 \cdot 2\text{H}_2\text{O} + \text{CO}_2$
- iii) H₂SO₄ so produced is used in lowering the pH of the soil
- Quantity of sulfur applied depends on pH and texture of the soil. Ordinary ground sulfur should be mixed to the soil with *desi* plough or disc several weeks before planting of the crop. Sulfur is suitable for soils up to pH 9.0. (Saline and saline alkali soils)

Iron Sulfate

It is also used in soils containing free calcium carbonate. It reacts as follows:

- $\text{FeSO}_4 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{SO}_4 + \text{FeO}$
- $\text{H}_2\text{SO}_4 + \text{CaCO}_3 \rightleftharpoons \text{CaSO}_4 + \text{H}_2\text{O} + \text{CO}_2$
- $\text{CaSO}_4 + 2\text{Na}^+(\text{micelle}) \rightleftharpoons \text{Ca}(\text{micelle}) + \text{Na}_2\text{SO}_4 \downarrow$

It is suitable for reclamation of saline alkali and alkali soils having pH up to 9.0.

In non-calcareous soils, H₂SO₄ formed may react as follows:

$$\text{H}_2\text{SO}_4 + 2\text{Na}^+(\text{micelle}) \rightleftharpoons 2\text{H}^+(\text{micelle}) + \text{Na}_2\text{SO}_4 \downarrow$$

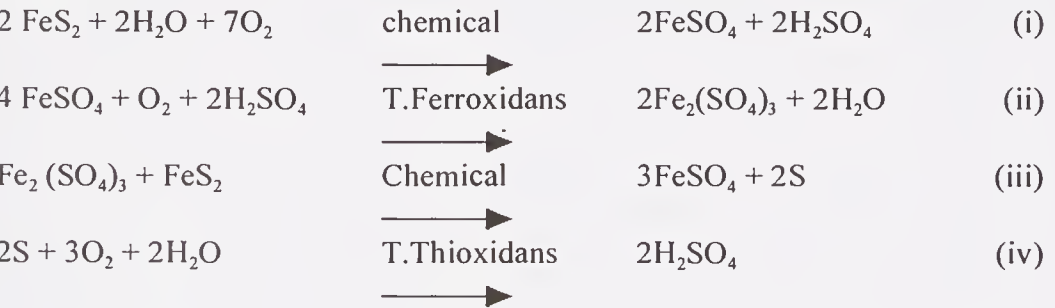
Limestone

Limestone is effective in soils having pH less than 7.5, since calcium carbonate becomes insoluble as the pH increases. Lime stone is dissolved in the soil solution and reacts rapidly as indicated in the reaction below:

$$2\text{Na}^+(\text{micelle}) + \text{CaCO}_3 \rightleftharpoons \text{Ca}(\text{micelle}) + \text{Na}_2\text{CO}_3$$

Pyrite

Pyrite is a mineral containing iron and sulfur (FeS₂). Pyrite is oxidized to sulfate. The oxidation is a chemical and microbiological process. It proceeds as follows:



Increasing the ratio of application of pyrite increases the surface available for oxidation and results in an increase in the amount of pyrite oxidized. Top dressing of pyrite increases its oxidation and is more effective. The temperature range between 25 to 45°C is considered optimum for activity of *Thiobacilli*. *Thiobacilli* is usually aerobic and their activity decline under oxygen deficiency

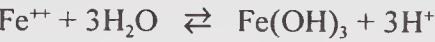
like waterlogging. *Thiobacilli* enhances the rate of oxidation of pyrites. The reaction based on calculation made by Jackson (1973) between gypsum and elemental sulfur may be extended for pyrite (in tonnes/ hectare - 15 cm depth) as shown below:

1 GR = 2.16 tonnes gypsum = 0.38 tonnes sulphur = 1.70 tonnes pyrite

Pyrites can also reclaim alkali soils by replacing their adsorbed sodium ion with the hydrogen ion of sulfuric acid produced during the oxidation of pyrites



The hydrogen clay so formed has good physical condition. The Fe^{++} ions released during the oxidation of pyrite acts as a proton donor and plays an important role in reducing pH of the soil. The reaction is as follows:



Pyrites should be grinded into small particles and broadcasted followed by a light irrigation. It takes about 4–6 weeks to oxidize on the surface of the soil after which it should be incorporated in to soil.

The effectiveness of all four chemical amendments mentioned above is compared as follows in Table 16.5.

Action of Gypsum or Sulfur Materials Takes Place as Follows

- Sodium attached to clay particles causes dispersion of particles which results in their close packing and water can not penetrate through it.
 - Gypsum or sulfur containing materials furnish soluble calcium which replaces sodium adsorbed on the exchange complex which allows soil particles to form floccules so that large pore space now formed allow water to pass through it.
- A combination of gypsum, sulfur and organic matter has been found useful. Addition of organic matter helps in improving soil structure. Organic matter also provide energy to soil bacteria that stimulate the oxidation of sulfur to sulfate form.

Use of Sulfuric Acid

In case of high alkalinity, reduction in pH can be brought about by the use of sulfuric acid. This is not very practical. The sulfuric acid produced reacts with sodium carbonate to produce sodium sulfate system. It encourages soil aggregation. Sulfuric acid solubilizes calcium from native CaCO_3 and replaces sodium by calcium on the soil exchange complex.

Use of molasses @ 2–3 tonnes/hectare along with 1–2 tonnes/hectare of press mud (a waste product of sugar industry) and 80–100 kg P_2O_5 /ha in the form of

Table 16.5. Efficiency of various material used to reclaim alkali soils compared to gypsum

Material		Tonnes of material equivalent to one tonnes of gypsum
Gypsum	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	1.00
Sulfuric acid	H_2SO_4	0.57
Sulfur	S	0.18
Pyrite	$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	1.62

basic slag has been found useful. Molasses provides energy for micro-organisms, which on fermentation produce organic acids. Addition of press mud produces soluble calcium.

Salt Precipitation Theory

The elimination of salts and exchangeable sodium from soils by leaching is a satisfactory method of reclaiming salt affected soils, but the leached salts are washed into ground waters making these waters saltier. Soils are subjected to salt problems. The leached salts could be precipitated at a depth of 0.9–1.8 metre (3–6 feet) where salts would form a layer of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) or carbonate ($\text{CaCO}_3, \text{MgCO}_3$) during dry periods and do not react as soluble salts. Thus, leaching water would be carrying less total salts in the lower layers. This is salt precipitation theory. On an average, 30% of the total salts may precipitate in this way. Most plant roots proliferate in the upper 30–60 cm from which they absorb water. The management of such soils lies in maintaining a uniform depth of wetting. Soils with shallow water table are not suited for this technique.

AGRONOMIC PRACTICES

For getting good yields of crop from salt affected soils, practices should be based on following aspects of management.

Soil Management

- Proper and careful levelling of land should be achieved before flooding for leaching. Where lands are sloppy, construction of dykes on the contours with a vertical interval, not exceeding 15 metre is essential for uniform spread of water and downward leaching of salts.
- Periodic soil testing is essential to know salt content before and after taking steps for soil improvement, gypsum requirement and fertility status of soil.

Water Management

- A high water content in the soil dilutes salts and lessens their toxic and osmotic effects.
- Frequent light irrigation is better than heavy irrigation for these soils.
- Soils that develop hard crusts must not be irrigated after planting.
- High water content during the germination and seedling stage enable plants to survive to the mature stage of growth. Also, adequate moisture at germination and at later stage of growth is necessary to avoid moisture stress.
- Quality of water is an important consideration for use on these soils. For heavy textured soils and salt tolerant crops, the maximum permissible limit for electrical conductivity (EC) of water is 15. ds/m, while, in light textured soils, water with EC up to 8 ds/m could be used for tolerant crops.
- Care should be taken to see that the ground water table at no time of the year is within 1.5 metre from the surface.
- If water contains more than 70% sodium, gypsum should be applied in water as well as in soil.
- The limits of quality ratings of water should be reduced to half, if water level

comes up within the root zone and soils have impeded internal drainage either on account of presence of hard pan, high amount of clay or other morphological reason.

- Best technique of water harvesting should be adopted.
- Use of brackish water: Brackish water is a water of salinity, high enough to significantly restrict its use, yet not prevent its use completely. Brackish water has 100-1000 ppm of chloride salts. Thus, regular leaching can prevent increase in soil salinity with constant use of such waters. Drying of soil should be avoided and water should be applied at a rate that exceeds evapotranspiration. Such waters (Brackish waters and water of low salt contents) may be mixed with fresh waters to get water of comparatively low salt content to use for irrigation.

Crops and Varieties

Crops and their varieties vary a great deal in their tolerance to salinity and alkalinity conditions. *Dhaincha* is a tolerant legume in these soils, rice is tolerant to flooding conditions and has a shallow root system. A list of salt tolerant crops has been given in Tables 16.6 to 16.14. The choice of crops is based on i]. The tolerance of salt ii]. Soil characteristics.

Manure and Fertilizers

Salt affected soils are deficient in organic matter and nutrients particularly nitrogen and zinc. Because of high pH, many plant nutrients are fixed up in unavailable forms. Green manuring with *dhaincha* and addition of farmyard manure results in increasing fertility and improving soil physical conditions. Application of fertilizers in conjunction with farmyard manure gives good results. This has been discussed in management of poor quality irrigation waters to follow next. *Dhaincha* has been found to be the best green manure crop in alkali soils because of its tolerance to salts and water logging, extensive root system, easy rotability and luxuriant growth. farmyard manure and gypsum when used singly or combined bring faster reclamation because a greater part of organic matter is hydrolyzed when farmyard manure is used. The maintenance of flooded condition for 15–30 days following incorporation of farmyard manure reduced ESP to a greater extent by minimizing the escape of CO₂ released during fast initial decomposition besides facilitating leaching of sodium replaced from the exchange complex (Swarup, 1980). Rice husk and straw is resistant to microbiological decomposition which enables it to keep the highly deteriorated alkali soil in good physical condition. Sawdust also lowers ESP.

Mechanism of Salt Tolerance

Plant tolerance to salt concentration is specific and based on observed facts like (i). Accumulation of high level of sodium and chloride in shoots, (ii). Exclusion of salt ions by the root cells. Wheat, barley, rye seems to possess this ability and (iii). Excretion of adsorbed salts from the plant by means of “salt glands”. Halophytes (salt loving plants) have this mechanism.

RELATIVE SALT TOLERANCE OF CERTAIN PLANTS

Plants differ in their salt tolerance. Salt tolerance of different crops, (Table 16.6 and 16.7), relative crop tolerance to soil sodicity (Table 16.8), tolerance of grasses and forage crops to alkali soil conditions (Table 16.9), tolerance of trees species to soil alkalinity (Table 16.10), boron tolerance limits for agricultural crops (Table 16.11), chloride tolerance of different crops (Table 16.12), tolerance of trees to soil salinity (Table 16.13), salt tolerance varieties of different crops (Table 16.14) have been presented.

HARMFUL EFFECTS OF POOR QUALITY IRRIGATION WATER

Quality of Irrigation Water

Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Salinity is one of the most important criteria for assessing quality of irrigation water especially under arid and semi arid region, where the rainfall is erratic and seasonal. About 127340 sq. km. land in the country falls in the arid and semi-arid zones in which surface water resources are limited. Irrigated agriculture is mainly based on ground water resources. Ground water contributes to about 40% of all irrigation. In Punjab, Haryana, Uttar Pradesh, Gujarat, Delhi and Rajasthan, the majority of well waters are reported to be of poor quality and have caused widespread deterioration of the land. In arid region water available for irrigation usually contains soluble salts which contains Ca^{++} , Mg^{++} , Na^{+} cations and anions like Cl^{-} , SO_4^{-} , HCO_3^{-} and CO_3^{-} and sometimes borate (BO_3^{-}) and nitrate (NO_3^{-}). The concentration and composition of dissolved constituents in water determine its quality for irrigation; i.e. the quality of water depends on the amount and kind of salt dissolved in it. Since water is the chief

Table 16.6. Salt tolerance of different crops

Highly tolerant	Moderate tolerant	Moderate tolerant	Highly sensitive
Barley	Spinach	Radish	Lentil
Rice (Transplanted)	Sugarcane		
Cotton	<i>Raya</i>	Broadbean	Chickpea
Sugarbeet	Rice (direct sown)	Cabbage	Beans
Turnip	Wheat	Cauliflower	Pea
Tobacco		Cucumber	Carrot
Safflower	Pearlmillet	Gourds	Onion
Taramira	Alfa alfa	Tomato	Lemon
Karnal grass	Oat	Sweet potato	Orange
Date palm	Blue panic	Sorghum	Grape
<i>Ber</i>	Para grass	Millets	Peach
	Rhodes grass	Maize	Plum
Casuariana	Sudan grass	Berseem	Pear
Tararix	Guava		Apple
Salvadora	Pomegranate,		

Source : Singh *et al.* (1992)

Table 16.7. Salt tolerance of different crops

Tolerant	Medium tolerant	Sensitive	Medium sensitive
<i>Fibre, grain and special crops</i>			
Barley (8.0)	Cowpea (4.9)	Bean (1.0)	Maize (1.7) Sugarcane (1.7)
Cotton (7.7)	Oat	Rice (3.0)	
Guar (8.0)	Safflower	Paddy	
Rye (11.4)	Sorghum	Sesame	
Sugarbeet (7.0)	Soybean (5.0)		
Wheat (8.6) (semi-dwarf)			
Wheat (5.9) (durum)			
<i>Grasses and forage crops</i>			
Bermuda grass (6.9)	Barley forage (6.0)		Alfaalfa (2.0), Berseem (1.5), Cowpea (2.50) forage, Sesbania (2.3)
	Rape Sudan (2.8) grass		
<i>Vegetables and fruits</i>			
	Beet, red (4.0)	Carrot Onion Pea	Bean (1.0), Cabbage (1.0), Cauliflower (1.8), Cucumber (1.1), Lettuce (1.7), Muskmelon Potato, Pumpkin (1.2), Radish (2.0), Sweet Potato (2.5), Tomato (0.9), Turnip Watermelon
<i>Woody crops</i>			
Date palm (4.0)	Fig, Olive,	Almond,	Castor bean, Grape (1.5),
<i>Jajoba</i>	Papaya	Apple (1.5),	Grape fruit (1.8), Pear
	Pineapple,	Mango,	
	Pomegranate	Apricot (1.6), Olive, Olengn (1.7), Plum (1.5) and Sapota	

Data in parenthesis indicate threshold ECe (ds/m). *Source:* After Mass, 1986

carrier of salts, its rating for irrigation purpose is of great importance. In India there is urgent need to give a fresh look to introduce new concepts of water quality due to following reasons:

- The population is increasing at an alarming rate. (In 1991 it was 844 millions, in 1996 it was around 950 millions and it is expected to be 1500 millions by 2050.) Excessive withdrawal of good quality water can lead to deepening of water table and deterioration of water quality. In the times to come more and more saline waters will have to be used for agriculture. Excessive withdrawal of good quality water in many pockets of Rajasthan, Gujrat, Karnataka, Punjab, Haryana etc. has led to deepening of water table and has created scarcity of water. To be self sufficient in the production of food, fodder, fuel, timber, sugar, cotton and other agriculture products, all available resources of irrigation water have to be used judiciously and scientifically.
- Ground water resources and their quality in some of the states and arid and semiarid regions show that good quality water is limited.

Table 16.8. Relative crop tolerance to soil sodicity or alkalinity

More than 50 Tolerant	Exchangeable sodium percentage Range*		
	30-50 20-30		Less than 20
	Moderately tolerant	Semi-sensitive	Sensitive
Rice	Mustard	Linseed	Bengalgram
<i>Sesbania</i>	Rapeseed	Groundnut	Soybean
Barley	Wheat	Garlic	Safflower
	Sunflower	Onion	Peas
	Sorghum	<i>Guar</i>	Lentil
	Pearlmillet		Urdbean
	Pigeonpea		

Source : Rao *et al.* (1994) :

* Relative crop yields are only 50% of the maximum in respective sodicity ranges

- The effect of irrigation water on soil properties is modified suggesting scope for using even highly saline waters.
- Different new methods of irrigation such as sprinkle, drip and pitcher methods have been introduced which require less water and help to use higher salinity waters.
- Canal waters have been introduced on a large scale in the arid and semi-arid regions. These waters raise the water table and reduce the salinity of ground waters. Conjunctive use of these two waters, i.e. canal and ground waters coupled with new methods of irrigation and planting salinity tolerant crops/trees requiring less waters will lead to better utilization of highly saline / sodic waters.
- Salt tolerance of crops at different stages of growth has also shown that even highly saline waters can be used.

Table 16.9. Comparative tolerance of grasses and forage crops to alkali soil conditions

Tolerant	Moderately tolerant	Sensitive
Karnal grass	Blue panic	Anjan grass
Rhodes grass	Setaria grass	Maize
Gatton paric	Hybrid napier	Cowpea
Bermuda grass	Sudan grass, oats	clusterbean (<i>Guar</i>)
Coastal Bermuda	Sudan grass	Dinanth grass
Para grass	Sorghum	
	Lucerne	
	Senji	
	Berseem	

Source: After Kumar, 1993. Note : Each column represents the tolerance in decreasing order

Table 16.10. Relative tolerance of tree species to soil alkalinity

Average pH (0–120 cm) ²	Fuelwood/ timber species	Fruit trees
More than 10.0	<i>Prosopis Spp.</i> <i>Acacia nilotica</i> <i>Casuarina equisetifolia</i> <i>Tamarix articulata</i>	<i>Achras japota</i>
9.0 to 10.0	<i>Perminalia arjuna</i> <i>Albizia lebbok</i> <i>Pongamia pinnata</i> <i>Sesbania sesban</i> <i>Cassia siarea</i> <i>Pithecellobium dulce</i>	<i>Punica granatum</i> <i>Zizyphus mauritiana</i> <i>Spindus laurifolius</i> <i>Emblica officinalis</i> <i>Psidium guajava</i> <i>Phoenix dactyliflora</i> <i>Aegle marmelos</i> <i>Prunus persica</i> <i>Syzygium cumini</i>
8.2 to 9.0	<i>Dalbergia sissoo</i> <i>Morus alba</i> <i>Grevillea robusta</i> <i>Azadirachta indica</i> <i>Tactona grandis</i> <i>Poplar deltoides</i>	<i>Pyrus communis</i> <i>Vitis vinifera</i> <i>Mangifera indica</i>

Source : Rao, et al. (1994)

Harmful Effects of Poor Quality Irrigation Water

If water containing excessive soluble salts is applied to the field, soils turn saline to alkali. Harmful effects of saline and alkali soils on plant thus become evident.

- These are depicted through increased osmotic pressure of soil solution, thus inhibiting uptake of water and nutrients from soil to plant roots and subsequently in plant system.
- Excessive sodium adsorbed by clay causes deflocculation, destroys soil structure resulting in poor circulation of air and water in the soil.

If soil contains free calcium carbonate, this is dissolved in irrigation water to release calcium ions. Since calcium ions are held by more tightly than sodium ions, this prevents adsorption of sodium by clay micelle. Therefore, irrigation water containing higher amounts of soluble salts may be used for irrigation, if soil contains enough calcium carbonate.

CRITERIA OF SUITABILITY OF WATER FOR IRRIGATION

The characteristics of irrigation water that appear to be important in determining its quality are:

- Total concentration of soluble salts in water
- Relative proportion of sodium to other cations, especially, calcium and magnesium as determined by
 - Sodium adsorption ratio (SAR)
 - Soluble sodium percentage (SSP)
 - Residual sodium carbonate (RSC)
- Concentration of Boron in irrigation water
- Salt index
- Chloride concentration
- Nitrate concentration
- Lithium concentration

Total Concentration of Soluble Salts in Water

The concentration of total soluble salts (TSS) are measured by electrical conductivity (EC) in siemens metre⁻¹ (Sm⁻¹) or decisiemens metre⁻¹ (dsm⁻¹) for soil solution or millisiemens metre⁻¹ (m Sm⁻¹) for waters. There is a direct correlation between salt content and EC, i.e. it increases with salt content. It has been found that electrical conductivity of the saturation extract of soil is 2 to 10 times as high as that of the electrical conductivity of the applied irrigation water. The increase in salt concentration is the result of continuous removal of moisture by plant roots and evaporation. Thus continuous use of moderate to high salt content irrigation water may result in saline conditions. If the soil is allowed to dry, salts will move to the surface with evaporating water instead of moving deeper in to the soil by leaching. If there is adequate leaching and soil is kept wetter, plants can tolerate a higher salt content. The values of EC and salt concentration are presented in Table 16.15.

Table 16.11. Boron tolerance limits for agricultural crops

Crop	Threshold ppm
<i>Sensitive</i>	
Grape fruit	0.5 – 0.75
<i>Moderately tolerant</i>	
Pea	1.0-2.0
Radish	1.0
Potato	1.0 – 2.0
Lettuce	1.3
Cabbage	2.0 – 4.0
Cauliflower	4.10
Garlic	0.75 – 1.00
<i>Tolerant</i>	
Alfa alfa	4.0 – 6.0
Sugarbeet	4.9
Tomato	5.7
<i>Very Tolerant</i>	
Sorghum	7.4
Cotton	6.0 – 10.0

Source : Mass, 1990

The total dissolved salts (TDS) can be converted into dS/ m units using following relations:
TDS (mg/l) = 640 EC (dS/ m)
EC values can also be used for inferring the salt concentration expressed in milli equivalents per litre and such relation for mixed soil solutions having EC upto 5 dS m⁻¹ is represented by : Total ions (meq litre⁻¹) = EC (dS m⁻¹) × 10. The categories of waters on the basis of their salt content (TDS) include following as suggested by Gupta *et. al* (2000).

Table 16.12. Chloride tolerance of different crops

Crop	Threshold Cl ⁻ Cone (Me/ l)
Bean, Onion, carrot, Radish, Lettuce, Turnip	10
Potato, Sweet Potato, Cabbage, Maize, Sugarcane, Spinach	15
Alfa alfa, Sesbania	20
Cucumber, tomato	25
Sudan grass, Rice, Paddy	30
Cowpea	50
Wheat, durum	55
Sorghum, Sugarbeet	70
Cotton	75
Barley	80

Source : After Mass, 1990

Fresh water	=	<500 mg litre ⁻¹
Marginal water	=	500–1,500 mg litre ⁻¹
Brackish water	=	1,500–5,000 mg litre ⁻¹
Saline water	=	>5,000 mg litre ⁻¹
Brine water	=	35,000 mg litre ⁻¹
Bitter water	=	> 350,000 mg litre ⁻¹

Relative Proportion of Sodium to other Cations, Especially Calcium and Magnesium

Sodium Adsorption Ratio (SAR): The classification of irrigation waters with regard to Sodium adsorption ratio (SAR) is based primarily on effect of exchangeable sodium on the physical conditions of the soil. For example, S4 waters were

Table 16.13. Relative tolerance of trees to soil salinity

Tolerant (EC 15-35 dS/m)	<i>Tamarix troupilii</i> , <i>T. articulate</i> , <i>Prosopis juliflora</i> , <i>Pithecellobium dulce</i> , <i>Parkinsonia aculeata</i> , <i>Prosopis juliflora</i>
Moderately tolerant (EC 15-25 dS/m)	<i>Callistemon lanceolatus</i> , <i>Acacia nilotica</i> , <i>A. pennatula</i> , <i>A. tortilis</i> , <i>Casuarina glauca</i> -13144, <i>C. glauca</i> 13987, <i>C. oasa</i> 27, <i>C. glauca</i> (FRI), <i>C. equisetifolia</i> (FRI), <i>Eucalyptus camaldulensis</i> , <i>Leucaena leucocephala</i> , <i>Erescentia alata</i> .
Moderately sensitive (EC 10-15 dS/m)	<i>C. cunninghamna</i> (FRI), <i>C. cunninghamna</i> (Aust.), <i>E. tereticornis</i> , <i>Acacia auriculiformis</i> , <i>Terminalia arjuna</i> , <i>Pongamia pinnata</i> , <i>Gueezuma</i> , <i>Ulmifolia</i> , <i>Leucaena ahannoni</i> , <i>Senna</i> , <i>Albizia carbea</i> , <i>Senna atomaria</i> .
Sensitive (EC 07-10 dS/m)	<i>Syzygium cumini</i> , <i>S. fruticosum</i> , <i>Tamarindus indica</i> , <i>Salix</i> spp., <i>Acacia deamii</i> , <i>Albizia guachepole</i> , <i>Aleleia herbertsmithii</i> , <i>Caesalpinia eriostachya</i> , <i>C. velutina</i> , <i>Haemaloxylon brasillto</i> .

Source : Rao et al. (1994)

generally considered unsatisfactory for irrigation purpose except at low and medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible. The soluble inorganic constituents of irrigation waters react as ions rather than as molecules. The principal cations are Ca^{++} , Mg^{++} and Na^{+} with small quantities of K^{+} . The alkali hazard involved in the use of water for irrigation determine the absolute and relative concentration of the cations. If the proportion of sodium is high, the alkali hazard is high. If calcium and magnesium is high, the hazard is low. The SAR of a solution is related to the adsorption of sodium by the soil. This is expressed by the equation

$$\text{SAR} = \frac{\text{Na}^{+}}{\sqrt{\frac{\text{Ca}^{++} + \text{Mg}^{++}}{2}}}$$

Table 16.14. Salt tolerant varieties of different crops

Crop	Varieties
Paddy	CSR-10, CSR-11, CSR-12, TR-8, CSR-13, CSR-19, CSR-20, Jaya, Saket-1
Wheat	Raj-3077, KRL 1-4, WH-157, Khurchia-65, HD-2009, HD-2285, HD-2329, WH-542, C-306, HD-2428, PBM-154
Barley	CSS-1, CSB-2, CSB-3, DL-200, Ratna, Jyoti, BH-97, DLS-48, BL-2, RS-17, RS-6, K-125, Ambar, DL-88, RD-2423
Mustard	Pusa bold, Varuna, Kranti, RBT-1, RBT-2, Pusa-Barani, Krishna, Prakash, BH-30, Vaishnev, Vardan, Rohini.
Sugarbeet	Romansakaya-07, Tribal, Poly reva.
Sugarcane	Co-453, Co-1341, Co-6801, Co-62329, Co-1111.
Guar	ROC-978, HG-75
Groundnut	SB-YI, K-3
Pearlmillet	HHB-60, MH-419, PHB-10, MBH-110, MH-179, CM-46, PSB-8, ICMS-7704, WCC-75
Cumin	UC-208, RZ-19
Cotton	H-777, F-414, LH-900, Bikaneri narma, G-J, G-27, AK-235, MCU-7, Laxmi, Sharda, HS-6, Pusa-31, FH-286, LM-886, AKM-4, Sangam, Amaravati

Source: Singh *et al.* (1992) and Rao *et al.* (1994)

Where Ca^{++} , Na^{+} , and Mg^{++} represent the concentration in millimoles per litre (m mole/l) of the respective ions. Their limits have been indicated in Table 16.16.

Research carried out on SAR aspect show that the compositions of the soil solution is affected by the interaction between the irrigation water and the soil which could cause precipitation (loss of Ca) or dissolution (gain in Ca). Since it is SAR_{sw} rather than SAR of irrigation water, which effects ESP, the SAR of the irrigation water as such has limited applicability as a sodic hazard criterion.

Adjusted SAR: Since the SAR of irrigation water as such does not take into account changes in solubility of calcium resulting from precipitation or dissolution reactions following irrigation. Its use may be misleading. Suarez (1981) gave a fresh look to the SAR equation and adjusted the calcium concentration of irrigation water to the expected equilibrium value following irrigation. This assumes a soil source of calcium from soil lime (CaCO_3) or the other soil minerals such as silicates and no precipitation of magnesium. Adjusted SAR shows the tendency for sodium to increase its proportion on the exchange site at the expense of other cations. It is estimated by the ratio of sodium content to the content of calcium plus magnesium in water. If the water contains HCO_3^{-} and $\text{CO}_3^{=}$ ions, these will precipitate Ca^{++} and Mg^{++} , which increase the SAR. The formula taking into account these changes is called the *adjusted SAR*. It is defined as

$$\text{SAR} = \frac{\text{Na}^{+}}{\sqrt{\frac{\text{Ca}^{++} + \text{Mg}^{++}}{2}}} [1 + (8.4 - \text{pHc})]$$

Where $\text{pHc} = (\text{pK}^1_2 - \text{pk}^1\text{c}) + \text{p}(\text{HCO}_3^{-} + \text{CO}_3^{=}) + \text{p}(\text{Ca}^{++} + \text{Mg}^{++})$
Where; $\text{pk}^1_2 - \text{pk}^1\text{c}$ is the sum of $\text{Ca}^{++} + \text{Mg}^{++}$ and Na^{+} ion concentration. $\text{P}(\text{HCO}_3^{-} + \text{CO}_3^{2-})$ is the concentration of carbonate and bicarbonate ions and $\text{P}(\text{Ca}^{++} + \text{Mg}^{++})$ is the concentration of Ca^{++} and Mg^{++} ions. Based on the adjusted SAR, irrigation water may be categorized as in Table 16.15.

Soluble Sodium Percentage: It refers to excess of sodium (Na^{+}) in proportion to Ca^{++} and Mg^{++} . Excess of Na^{+} increases alkali hazards. It is expressed as follows:

$$\text{Per cent sodium} = \frac{\text{Na}^{+} \times 100}{\text{Ca}^{++} + \text{Mg}^{++} + \text{K}^{+} + \text{Na}^{+}}$$

It is categorised as

Per cent Sodium	Class
<20	Excellent
20-40	Good
40-60	Permissible
60-80	Doubtful
>80	Unsuitable

Residual Sodium Carbonate: In waters, containing high concentration of bicarbonate ions, there is a tendency for Ca^{++} and Mg^{++} to precipitate as carbonates. This can be shown as $\text{RSC} = (\text{CO}_3^{-} + \text{HCO}_3^{-}) - (\text{Ca}^{++} + \text{Mg}^{++})$, where CO_3^{-} , HCO_3^{-} , Ca^{++} and Mg^{++} represents the concentration in millimoles/ litre (m moles/l) of respective ions.

Studies have revealed that RSC concept is questionable because of the assumption of quantitative precipitation. Also RSC from carbonate is more harmful than bicarbonate. RSC, thus has limited quantitative value. Rainfall, soil texture and plant species to be grown has great impact in deciding the limits of RSC for suitability of irrigation water in a particular area. For example studies conducted at CSSRI has revealed that water up to RSC 5.0 meq/l can be used where rainfall is 70 to 90 cm per annum.

Concentration of Boron in Irrigation Water

Boron is essential to plant growth but is exceedingly toxic at concentrations only slightly above optimum. The occurrence of boron in toxic concentrations in certain irrigation water make it necessary to consider this element in assessing the quality of water. Boron frequently occurs in toxic concentration along with other salts that are present in saline soils. Many ground waters in arid and semi-arid regions of India contain boron in toxic amounts. A significant relationship between B content and salinity / alkalinity hazards of waters have been observed (Paliwal and Mehta 1973).

A quantity of boron sufficient to be toxic may remain after the concentration of other salts is reduced to a safe level. Boron can not be precipitated or easily removed from water. The only known remedy is to dilute high boron water or to grow boron tolerant crops (Table 16.11). If water-soluble boron is more than 1 ppm, it is considered unsuitable for irrigation.

Salt Index

It is also used for predicting sodium hazards. It is the relation between Na^{+} , Ca^{2+} and CaCO_3 present in irrigation water.

$$\text{Salt index} = (\text{Total Na}^{+} - 24.5) - [(\text{Total Ca} - \text{Ca in CaCO}_3) \times 4.85]$$

Where all the quantities are expressed in ppm. The salt index is negative (–24.5 to 0) for irrigation water of high quality and any positive value of the salt index is harmful for irrigation purpose.

Chloride Concentration

Specific ions, which deserve special attention, are chlorine and fluorine. Continuous feeding of fodder and grain by animals and human beings can cause

Table 16.15. Soil classes of irrigation water based on their adjusted SAR

Class	Adjusted SAR
Low	<10
Medium	10-20
High	20-30
Very high	>30

fluorosis. Fluorine from irrigation waters is adsorbed by soil or interaction with calcium reduces its uptake by plants.

Chloride exists in soils as chloride ion (Cl⁻), a very soluble and mobile ion. Chloride may accumulate in toxic amounts. Soluble salts, which hinder plant growth, have chloride as one of the most numerous anion. Irrigation water containing high chloride contents may cause salt burn on the foliage. It can be used as a factor in regional water classification:

$$\text{Chloride concentration (me l}^{-1}\text{)} = \frac{\text{Cl}^{-} + \text{NO}_3^{-}}{\text{CO}_3^{2-} + \text{HCO}_3^{-} + \text{SO}_4^{2-} + \text{Cl}^{-} + \text{NO}_3^{-}}$$

It can be categorised as:

Chloride concentration (me l ⁻¹)	Water quality
>4	Excellent
4–7	Moderately good water
7–12	Slightly usable
> 12 above	Not suitable for Irrigation water

Chloride tolerance of different crops has been given in Table 16.10.

Nitrate Concentration

Ground waters may contain up to 100-ppm nitrate, which is hazardous for irrigation (more than 100-ppm nitrate nitrogen is considered hazardous to human health). Higher nitrate accumulation may cause diseases in ruminants grazing on such lands. Since all nitrogen fertilizers are very soluble in water, nitrates move readily in the water. Nitrogen is also added from decomposing organic matter. Forage crops and leafy vegetables when grown with nitrate-containing waters, accumulate high levels of NO₃⁻ and organic acids such as malate and oxalate, to lower their food quality. It was observed that a wheat crop grown with water containing high NO₃⁻ contents was not grazed by the animals. Nitrate concentration may increase through:

- Soil solution (nitrate is dissolved)
- Water available for run off and leaching through the soil.
- Soil permeability

Lithium Concentration

It has been found that small concentrations (0.05 – 1.0 ppm) of lithium in irrigation water produced toxic effect on the growth of citrus crops. It has also been reported that saline soils of varying degrees found in India contains lithium up to 2.5 ppm

From the above it can be seen that appraisal of water quality is not a simple exercise. One has to keep all the parameters in mind while judging the quality of irrigation water. Climate, soil properties, crops / plants to be grown, available resources including rain water, good quality canal water, method of irrigation are the important points which also deserve consideration.

CLASSIFICATION OF IRRIGATION WATER

Irrigation water can be classified from the point of view of salinity and sodium hazards as shown in Table 16.16.

Classification based on EC and SAR values

EC water classes:

- C1 -Low salinity water, can be used for most crops.
- C2 -Medium salinity water, can be used with moderate leaching.
- C3-High salinity water, this water can not be used on soil with restricted drainage
- C4 -Very high salinity water, this water is not suitable for irrigation. If used soil must be permeable and drainage adequate.

SAR Water Classes

- S1-Low sodium water can be used on all soils, with little danger of development of harmful level of exchangeable sodium.
- S2-Medium sodium water, can produce hazards with fine textured soils, which have high cation exchange capacity, especially with low leaching conditions.
- S3 - High sodium water, may produce harmful level of exchangeable sodium in most soils. It requires special management practices such as good drainage, high leaching and organic matter additions. Exchangeable sodium should be replaced in soils by the use of chemical amendments
- S4 - Very high sodium water, not suitable for irrigation. This water can be used with the addition of gypsum or other amendments.

The modified classification of irrigation waters proposed by U.S. salinity laboratory, 1954 (after earlier classification given by Wilcox, 1948) based upon the electrical conductivity and SAR values.

- It may be seen from the quality of water becomes poorer as salinity class and sodium hazards as revealed by increase in SAR, increases. The curves are given a negative slope to take into account the dependence of sodium hazards on the total concentration. Thus a water with a SAR value of 9 and

Table 16.16. Classification of irrigation water according to EC, Salt concentration, SAR, RSC, and Boron content

Water class	EC in millisiemens/ metre at 25°C	Salt Concen- tration (%)	SAR	RSC	ppm of boron in water		
					Sensitive crops	Semi tolerant crops	Tolerant crops
Low	<25 (C1)	< 0.16	<10 (S1)	< 1.25	< 0.33	< 0.67	< 1.0
Medium	25–75(C2)	0.16–0.50	10–18(S2)	1.25–2.5	0.33–0.67	0.67–1	1–2
High	75–225(C3)	0.50–1.50	18–26(S3)	>2.5	0.67–1.00	1–2	2–3
Very high	>225(C4)	1.50–3.00	>26(S4)		>1.00	>2	>3

conductivity less than 68 is classed with regard to sodium hazards as S1 water and so on. Using the SAR and EC value as coordinates, locate the corresponding point in the diagram. The position of the point determines the quality classification of water.

- Classification of the irrigation water by Food and Agriculture Organization (FAO): FAO has given certain guidelines as presented in Table 16.17. These salinity boundaries show the C1 and C2 waters as “no problem” and most of the C4 category water and higher salt as a severe problem.
- Classification of irrigation water suggested by CSSRI, Karnal and Recommendation of AICRP and CSSRI Karnal and PAU, 1990 under project on saline water (Table 16.18 and 16.19).

Most of the classes in classification suggested by USDA Handbook-60 based on electrical conductivity (EC) and sodium adsorption ratio (SAR) do not hold good under field conditions especially in arid and semi-arid regions of the world. In India, lot of research work has been carried out on quality of water and its suitability for irrigation. Waters used for irrigation may be categorized as saline water and sodic water.

Saline Water

A majority of saline waters have $EC < 10$ ds/m and $SAR < 20$ (mmol/l). The salts are mainly chloride and sulphate of sodium, magnesium and calcium. A small amount of bicarbonates are also commonly present and residual sodium carbonate (RSC) is often absent or less than 2.5.

Table 16.17. Guidelines for irrigation water quality established by the Food and Agriculture Organization (FAO)

Water constituent	No problem	Moderate	Severe
Salinity (dsm-1):			
Permeability (rate of infiltration affected)	< 0.70	0.70–3.00	> 3.0
Salinity (dsm ⁻¹)	<0.5	0.5–2.00	> 2.0
Adj., SAR; soils are :			
Dominantly montmorillonite	<6	6–9	>9
Dominantly illite – vermiculite	<8	8–16	>16
Dominantly kaolinite-sequioxides	<16	16–24	>24
Specific ion toxicity:			
Sodium (as adj. SAR)(sprinkler)	<3	3–9	>9
Chloride (mmol L ⁻¹) (sprinkler)	<3	>3	>10
Boron (mmol 2 ⁻¹) as B	< 0.70	0.70–3.0	>3.0
Miscellaneous			
NO ₃ ⁻ - N or NH ₄ ⁺ - N (mmol L ⁻¹)	<5	5–30	>30
HCO ₃ ⁻ (mmol L ⁻¹) as damage by over head sprinkler	<1.5	1.50–8.5	>8.5
pH	6.5–8.4		0-5,9.5+

Table 16.18. Guidelines for using poor quality irrigation water (joint recommendation of AICRP-Saline Water, CSSRI, Karnal and PAU, 1990)
Saline Water (RSC 2.5 meq/l)

Soil texture (% clay)	Crop tolerance	Upper limit of EC_{iw} (ds/m) in rainfall regions (mm)		
		350	250–550	55–750
Fine (>30)	S	1.0	1.0	1.5
	ST	1.5	2.0	3.0
	T	2.0	3.0	4.5
Moderately fine (20–30)	S	1.5	2.0	2.5
	ST	2.0	3.0	4.5
	T	4.0	6.0	8.0
Moderately Coarse (10–20)	S	2.0	2.5	3.0
	ST	4.0	6.0	8.0
	T	6.0	8.0	10.0
Coarse (<10)	S	6.0	3.0	3.0
	ST	6.0	7.5	9.0
	T	8.0	10.0	12.5

(S- sensitive, ST-semi-tolerant, T-tolerant)

Sodic Water

In case of sodic waters, the EC is usually not very high (<4ds/m) but sodium carbonate and bicarbonate constitute a significant proportion of total salts. RSC exceeds 2.5 me/l.

The Salient Features of FAO Guidelines are as Follows

- It refers to the sodicity problem as permeability. It includes salt concentration because at very low salt levels, flocculation decreases which reduces

Table 16.19. Alkali waters (sodic waters containing Residual sodium carbonate 2.5 meq/l and EC_{iw} 4.0 ds/m)

Soil texture (% clay)	Upper limits of		Remarks
	SAR (m mol/lre ⁻¹)	RSC (meq litre ⁻¹)	
Fine (>30)	10	2.5-3.5	Limits pertain to <i>kharif</i> fallow <i>rabi</i> crop rotation when annual rainfall is 350–550 mm.
Moderately fine (20–30)	10	3.5–5.0	When the waters have Na 75%, Ca+Mg 25% or rainfall is 55 mm, the upper limits of the RSC range becomes safe.
Moderately Coarse (10–20)	15	5.0–7.5	For double cropping, RSC neutralisation with gypsum is essential based on quantity of water used during the <i>rabi</i> season.
Coarse (<10)	10-20	7–5–10.0	Grow low water requiring crops during <i>kharif</i> . Avoid growing rice.

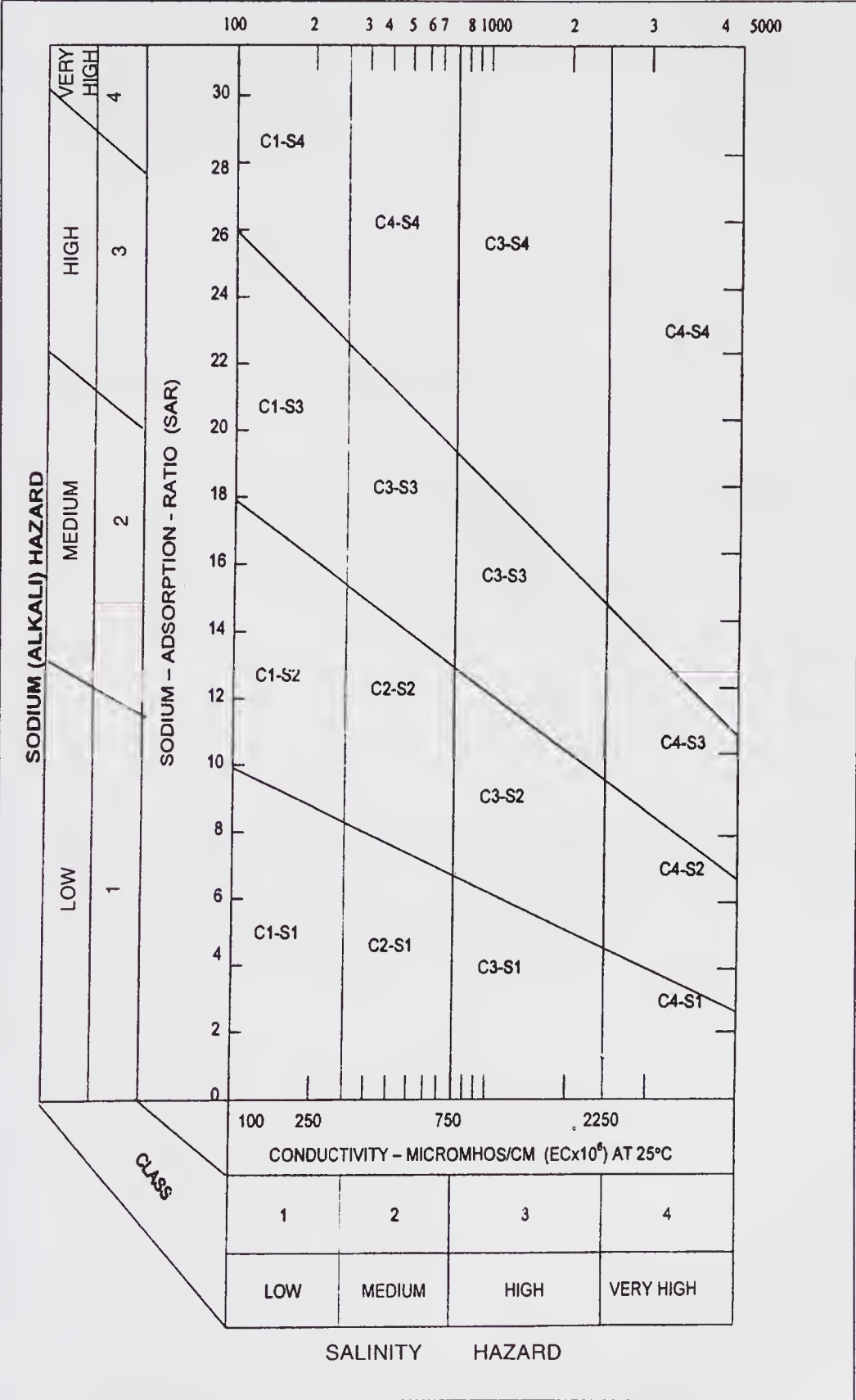


Fig. 16.1. Diagram for the classification of irrigation waters

Table 16.20. Grouping of poor quality ground waters

Water quality class		EC _{iw}	SAR _{iw}	RSC
Main	Subclass	(dSm ⁻¹)	(mmol litre ⁻¹)	(meq litre ⁻¹)
Good		<2	<10	<2.5
Saline	Marginally saline	2-4	<10	<2.5
	Saline	>4	<10	<2
	High SAR saline	> 4	>10	<2.5
Alkali	Marginally alkali	<4	<10	2.5-4.0
	Alkali	<4	<10	>4.0
	Highly alkali	Variable	>10	>4.0

Source: Gupta et al. (2000) Natural Resource Management for Agricultural Production in India

permeability. Waters with less than 0.2 dsm⁻¹ cause poor permeability.

It recognizes the problem of sodium in relation to different clays dominant in a soil. The problem is severe with expanding clays like montmorillonite and less so with kaolinite and sepioids.

- It gives a true picture of the sodicity of the soil as it accounts for adjusted SAR
 - It accounts for chloride, bicarbonate, boron, nitrates which are important in assessing the quality of irrigation water.
 - Textural criteria should be applicable for all soil layers down to at least 1.5m depth.
 - In areas where ground water table reaches within 1.5 m at any time of the year or a hard subsoil layer is present in the root zone, the limits of the next finer textural class should be used.
 - Fluorine is at times a problem and limits should be worked out.
- Gupta *et al.* (2000) have suggested the following grouping of poor quality ground waters. (Table 16.20).
- Integrating the effect of soil texture and rainfall into leaching fraction and of SAR and RSC in adjusted SAR on adjusted SCAR (sodium to calcium activity ratio); Gupta (2001) proposed that irrigation waters may be classified into five classes each on the basis of EC as (A) <1.5 (B) 1.5–3.0 (C) 3.0–5.0 (D) 5.0–10.0 and (E) > 10.0 dSm⁻¹ and four classes on the basis of adjusted SAR/SCAR viz. I (<10), II (10–20), III (20–30) and IV (>30) (Table 16.21).

METHODS FOR IMPROVEMENT AND MANAGEMENT OF POOR QUALITY IRRIGATION WATER

The change in quality of irrigation water is technically not feasible. It is also not economically viable to improve irrigation waters on large scale. The effect of irrigation water on soil depends on the composition of water, the properties of soil and climatic conditions, i.e., annual rainfall, distribution of rainfall and annual evaporation. The water containing lower concentration of salts, carbonate and bicarbonate ions and boron but on the other hand having high proportion of

Table 16.21 New clasification of irrigation water

Leaching fraction or Leaching requirement	Permissible ECe (dSm ⁻¹)	Limits Adjusted SAR/SCAR
0.1	<1.5 (A)*	<10 (I)
0.2	1.5–3.0 (B)	10–20 (II)
0.3	3.0–5.0 (C)	20–30 (III)
0.4	5.0–10.0 (D)	30–40 (IV)
0.5	>10 (E)	>40 (V)

*. Figures in brackets indicate class Gupta (2001)

divalent cations (Ca⁺⁺+ Mg⁺⁺) over sodium are considered to be of good quality. The ESP of the soil is also closely associated with SAR of irrigation water. The following measures should be adopted for improvement and management of poor quality irrigation water.

Selection of salt tolerant crops and their varieties: (listed in Tables 16.6 to 16.14)

Seed bed preparation and planting techniques to minimize local accumulation of salt in the vicinity of seeds

- Deep plowing should be done. It is also necessary to break the hardpan if any in the soil profile. Land should be well levelled for uniform distribution of water.
- Sloping ridges are best for saline conditions because the seed can be safely planted on the slope below the zone of high salt accumulation.
- Poor germination, high mortality of young seedlings and poor tiilering are common features when crop is grown with poor quality waters. So higher seed rate and close spacing is advisable. More than 25% recommended seed rate for normal soil ensures a good crop stand in case of wheat, barley, mustard, cotton and pearlmillet.

Table 16.22. Combined effect of zinc levels and quantities of irrigation water on grain and straw yields of wheat

Zinc sulphate levels (kg/ha)	Qualities of irrigation water		
	W ₁	W ₂	W ₃
10	23.17(49.23)*	27.23(44.43)	20.60(41.30)
20	26.13(56.67)	24.23(49.90)	22.83(46.33)
30	25.30(54.90)	25.00(53.37)	23.40(48.57)
40	24.83(51.33)	24.67(51.70)	24.13(50.67)
CD at 5%	1.07 (2.41)		

Source: Lal and Lal (1980) * Figure in parenthesis denote straw yield of wheat W₁, EC 2.1 ds/m; SAR; 23.9; W₂, EC 4.2 ds/m; SAR, 30.2; W₃, EC 6.3 ds/m, SAR, 36

- Furrow planting helps in getting better yield under saline condition because salts accumulate on the ridges. If ridge and furrow method is followed, seeds could be sown either in the furrow or north side of the ridge. About 20 cm high ridges are made at the desired spacing. Seeds should be sown on the north side of the ridges (i.e. east-west directions) at a height of 10 cm.

Irrigation to Maintain a Relatively Higher Level of Soil Moisture and to Satisfy the Leaching Requirement of Soils

The amount of water applied should be sufficient to supply to crop and satisfy the leaching requirements. Over supply of water may lead to high water table and low water may lead to accumulation of salts. Therefore, a proper relation between irrigation, leaching and drainage must be maintained in order to prevent irrigated lands from becoming waterlogged and salt affected. A heavy pre-sowing irrigation is useful to leach down the accumulated salts from the root zone. This will improve the germination percentages.

Green Manuring by *Dhaincha*

Dhaincha as green manuring crop improves physical properties of soil. Following this practice significant increase in yield of crops particularly wheat has been obtained. Addition of organic manure is useful when the crops are being grown with poor quality waters.

Application of Fertilizers

Fertilizers reduce the adverse effect of salinity and alkalinity of irrigation water (only at low levels of salinity and alkalinity). The response of fertilizer application decreases as the salinity and SAR of irrigation water increases. Fertilizer should be applied @ 1.25–1.5 times the normal rate of their application and in split doses to improve crop yields. Application of zinc also reduces the adverse effect of higher salinity and sodicity (Table 16.22) with low salinity waters. It indicates that application of zinc @ 20 kg ZnSO_4/ha mitigated the adverse effect of higher salinity and sodicity of water on wheat grown on loamy sand soils. CAN, ammonium sulfate, ammonium sulfate nitrate and urea can be used to lower the adverse effect of salinity and alkalinity. At higher salinity CAN is better than others. Split application of nitrogen should be done to reduce the nitrogen losses through volatilization and denitrification. In case of sodic soils and waters nitrogen should be applied in three splits 1/3 at sowing, 1/3 at tillering and rest at flowering stage. Phosphorus should be applied through DAP.

Use of Farmyard Manure

Application of well-decomposed farmyard manure is useful for both saline and sodic waters. For sodic water, use of farmyard manure alongwith gypsum is more beneficial.

Dilute and Cyclic Use of Good and Saline Waters

When good quality water is limited, then it should be properly utilized which can be done as follows.

- Presowing and first irrigation after germination should be done with good

quality water. Later on saline water can be used.

- Poor quality water can be mixed with good water. When irrigation is to be applied, both type of waters can be pumped simultaneously
- Conjunctive use of good water with saline or sodic water.

Improved Irrigation Methods

If water quality is poor, use of drip or pitcher irrigation has been found to be useful. Pitcher irrigation helps to keep the soil moist. Crops are able to tolerate more saline condition if moisture levels are maintained around field capacity level. Planting of fruit trees in arid region with drip or pitcher irrigation has great potential. At CSSRI, the use of pitcher irrigation for two year in sandy soil of Rajasthan promoted initial growth of *khejri* (*P. cineraria*) and subsequently establishes it. Once the roots moved to deeper soil layers irrigation is not required.

Use of Mulches

Use of mulches and intercultural operation if practiced, reduces water requirement of crops. Thus with saline water, salinity develops at a relatively lesser intensity.

Use of Brackishwater

Irrigation with moderate salty water or brackishwater is a beneficial practice. It is done with the aim to keep the soil near field capacity, dilute the concentration of salts to prevent foliage from harmful effect of salts and to leach the salts below the root zone. This is achieved by application of water at or below the soil surface so that soil surface is constantly moist but below field capacity and soil aeration is also good. Enough water is added to keep salts moving downward to avoid salt build up in the root zone. The successful use of brackishwater depends on the texture of the soil. This practice is more successful in coarse textured soils. However, the indiscriminate use of these waters without any amendment causes soil sodification. According to Yadav and Kumar (1995) sodic waters constitute 37% of the underground brackish waters in some states of north and north western India (Table 16.23).

Table 16.23. Per cent distribution of brackish waters in India..

State	Categories		
	Saline	Sodic	Saline-Sodic
Punjab	22	54	24
Haryana	24	30	46
Rajasthan	16	35	49
Gujarat	20	28	52
Average	20	37	43

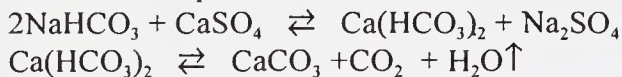
Source : Yadav and Kumar (1995)

Treatments with amendments

Use of gypsum: In water, containing excess of sodium, gypsum can be successfully used. With the addition of gypsum, proportion of sodium to other ions is decreased. Adverse effect of Na can be mitigated by narrowing down Na/K ratio in the water by way of adding potassic fertilizers. Gypsum can be applied by :

- Keeping gypsum lumps or powdered gypsum in bags in small tanks constructed at the mouth of tube well or water passage.
- Besides, gypsum can be mixed in soil to be irrigated,
- A saturated solution of gypsum may be added at a constant rate to flowing water. pH of the soil should also be checked before application of gypsum.

The reaction takes place as follows:

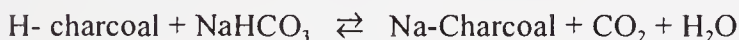
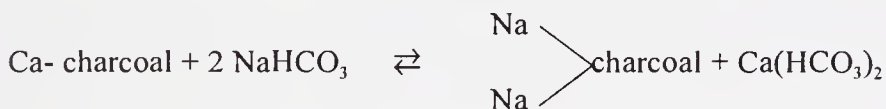


CaCO_3 being soluble can be leached. Use of gypsum has been successfully made to mitigate the adverse effect of sodicity of water or the soil.

Water containing toxic amounts of boron can be reduced by mixing them with gypsum. Sodium borate present in the soil is converted to calcium borate, which being soluble can be removed below the root zone. The application of gypsum results in a decrease in boron content of irrigation water.

Use of ion exchange resins

Water containing excess amounts of sodium is passed through high cation exchange capacity calcium and hydrogen charcoal. Charcoal absorbs sodium ions, the reaction is as follows:



The used charcoal may again be converted in to hydrogen charcoal by treating it with dilute acids.

References and Suggested Readings

- Abrol, I.P. and Bhumbra, D.R. (1971). *World Soil Resources Rep.* **41** : 42–51.
- Annual Reports (1985–88). *AICRP On Management of Salt Affected Soil, and Use of Saline Water in Agriculture*, Agra.
- Agarwal, R.R., Yadav, J.S.P. and Gupta, R.N. (1982). *Saline and Alkali Soils of India*, ICAR, New Delhi.
- Bernstein, L. and Francois (1973). *Soil Sci. Soc. Am. Proc.* **37** : 931–943.
- Bhargava, G.P (1989). *Salt Affected Soils of India – A Source Book*. Oxford and IBH Publishing Co., New Delhi.
- USDA. Diagnosis and Improvement of Saline and Alkali Soils. *Agriculture Hand book No. 60 USDA*, Oxford and IBH Publishing Company Pvt. Ltd., New Delhi.
- Eaton (1950). *Soil Science*. **69** : 123–133.
- Gupta, S.K., Minhas, P.S., Sondhi, S.K., Tyagi, N.K. and Yadav, J.S.P. (2000). Natural Resource Management for Agriculture, pp 163–165. *International Conference on Managing Natural Resources for Sustainable Agricultural Production in the 21 century*, 14–18 Feb. 2000, New Delhi.

- Gupta I.C. (2001). Saline Water Resources of Rajasthan Souvenir 200. *66th Annual Convention of ISSS at Udaipur*. pp 71–91.
- Jackson, M.L. (1973). *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi.
- Kumar, A (1993). Grasses and forage crops for salt affected soils (*In*) *Salt Affected Soils and Crop Production: A Modern Synthesis*, pp 225–262. Agrobotanical Publishers, Bikaner.
- Lal, P and Lal, P (1980). *International Symposium on Salt Affected Soils*, pp 404–408. Karnal, India.
- Mabbutt, J.A. (1984). *A New Global Assessment of Status and Trends of Desertification, Environmental Conservation*, Vol III, No 2. The Foundation of Environmental Conservation, Switzerland.
- Mass, E.V (1986). *Applied Agricultural Research* **1** : 12–26.
- Mass, E.V. (1990). Crop salt tolerance of plants. *In Agricultural Salinity Assessment and Management Manual*, pp 262–304. Tanj, K.K. (Ed.) ASCE, New York.
- Mehta, K.K. and Paliwal, K.V. (1971). *Oryza* **8** : 303–8.
- Paliwal, K.V. and Mehta, K.K. (1973). *Indian Journal of Agricultural Sciences*, **39** : 1083–7.
- Rao, D.L.M., Singh, N.T., Raj, K. and Tyagi, N.K. (Ed.) (1994). *Salinity Management for Sustainable Agriculture*, CSSRI, Karnal.
- Richards, L.A. (1954). Diagnosis and Improvement of Saline and Alkali Soils. *Agriculture Handbook* 60. USDA, Washington D.C.
- Singh, K.N., Sharma, S.P. and Rao, K.V.G.K. (1992). *Technical Bulletin No. 17*, CSSRI, Karnal.
- Suarz, D.L. (1981) *Soil Science Society American Journal*. **45** : 469–75.
- Swarup, A. (1980). *Journal of Indian Society of Soil Science* **28** : 532–4.
- Velayutham, M. and Bhattacharya, T. (2000). From Natural Resource Management for Agriculture page 92. *International Conference on Managing Natural Resources for Sustainable Agricultural Production in the 21st century*, 14–18, Feb. 2000, New Delhi.
- Vohra B.B. (1987). National resource management need for urgent action. *Proceedings of National Symposium on Remote Sensing of Land Transformation*, ISRS, I – IV. Dehradun. India.
- Yadav, H.D. and Kumar, V. (1995). Reclamation and management of waterlogged saline soils. (*In*) *National Seminar Proceedings*, CSSRI, Karnal and CSS, Haryana Agricultural University, Hisar.

QUESTIONS

Q. 1. Fill in the blanks

- i) Salinity is measured in terms of _____.
- ii) ESP of less than 15, parallels to SAR of less than _____.
- iii) The increased _____ of soil solution inhibits uptake of water and nutrients from the soil to plant system.
- iv) If water soluble boron is more than _____ ppm, it is considered unsuitable for irrigation
- v) If RSC values are more than _____, the irrigation water is categorized as high RSC water
- vi) Diagram for classifying irrigation water is based on _____ and _____.
- vii) _____ ion adversely effects uptake of Ca^{++} and Mg^{++} by plants.

- viii) Salt affected soils are deficient in nutrients particularly nitrogen and _____.
- ix) More than _____ ppm nitrate nitrogen is considered hazard to human health
- x) Any soil having pH greater than 7.0 is called _____.

Answers

(i) electrical conductivity (ii) 13 (iii) osmotic pressure (iv) 1 (v) 2.5 (vi) electrical conductivity and SAR (vii) sodium (viii) zinc (ix) 100 (x) alkaline soil.

Q.2. Choose the correct answer

- i) The selection of the critical values for EC of 4 is based on the expected salt damage to crops/ higher concentration of salts which deteriorate soil.
- ii) Saline soils are in a flocculated/ de-flocculated state.
- iii) Flow of water and nutrients takes place from lower/higher concentration towards higher concentration.
- iv) Usually plant tolerances to salts increase/ decrease with their maturity.
- v) Boron is strongly/ not strongly adsorbed by soil constituents.
- vi) Brackish water has chloride/nitrate salts.
- vii) Use of gypsum results in a decrease/ increase in boron content of irrigation water.
- viii) If water contains more than 70 / 30 percent sodium, gypsum should be applied in water as well as in soil.
- ix) Electrical conductivity of saturation extract of soil is higher / lower than that of irrigation water.
- x) The soluble inorganic constituents of irrigation water react as ions / molecules.

Answers

(i) salt damage to crops (ii) flocculated (iii) lower (iv) increase (v) strongly (vi) chloride (vii) decrease (viii) 70 (ix) higher (x) ions.

Q. 3. Define the following

- (i) Gypsum requirement (ii) Alkaline soil (iii) Salinization (iv) Alkalization

Q. 4. Differentiate between

- (i) Reclamation of a saline and alkali soil (ii) S₂ and S₃ waters (iii) S.A.R. and Adjusted S.A.R.

Q. 5. Write short notes on

- (i) SAR (ii) SSP (soluble sodium percentage) (iii) Adjusted SAR (iv) Use of brackish water (v) Degraded alkali soils (vi) Leaching requirement (LR) (vii) Salt precipitation theory (viii) Use of brackish water (ix) RSC (Residual sodium carbonate) (x) Use of ion exchange resins in improving quality of saline water.

Q. 6. Comment on the following statements

- i) Saline and alkali soils usually occur in arid and semi arid regions
- ii) Presence of sodium in soil increases pH.
- iii) *Dhaincha* is one of the best green manuring crop in alkali soils
- iv) Irrigation water containing higher amounts of soluble salts may be used for irrigation if the soil contains free CaCO_3
- v) Determination of boron concentration in irrigation water is a important criteria in evaluating quality of irrigation water
- vi) Management of poor quality irrigation water is more important than improving its quality
- vii) Use of saline water depends on the type of soil and crops to be taken
- viii) Water containing toxic amounts of boron can also be reduced by mixing them with gypsum
- ix) Limestone is suitable in the reclamation of soils having pH less than 7.5
- x) The electrical conductivity of saturation extract of a soil is more (2 to 10 times) than that of the applied irrigation water
- xi) Use of gypsum has been made to mitigate the adverse effect of sodicity of water on the soil
- xii) Use of pitcher irrigation has been found useful to improve poor quality waters.

Q. 7. Answer the following in brief

- i) Enlist common cation and anions to be considered in the appraisal of saline and alkali soils
- ii) How soils sodicity adversely affects crop growth.
- iii) What are the general rules to reclaim salt affected soils
- iv) How mulching is beneficial practice under saline alkali condition
- v) Enlist trees suitable under saline alkali soils
- vi) Enlist sodium and boron tolerant crops
- vii) Give chemical reactions of gypsum, sulfur, iron sulfate, limestone, pyrite in the reclamation of saline alkali soils
- viii) What is the mechanism of salt tolerance
- ix) Enlist characteristics that determine quality of irrigation water
- x) How does use of gypsum improves quality of irrigation water? Also show chemical reactions
- xi) Enlist the salient features of determining quality of water as established by FAO.

Q. 8. Answer the following in detail

- i) Give classification of irrigation water based on their electrical conductivity, SAR, RSC and boron
- ii) Explain the causes of formation of saline and alkali soils
- iii) Explain methods for improvement and management of poor quality irrigation water
- iv) Explain the effect of salinity and alkalinity on the growth of crops. □

Acid Soils

Acid soils are developed generally in areas of high rainfall (common in humid regions) due to leaching of bases. Soil pH falls below pH 7.0 due to active acidity. In these soils, the concentration of H^+ ions exceeds that of OH^- ions. The concentration of hydrogen and aluminium ions is increased. These soils may contain large amount of soluble Al, Fe and Mn.

In India, acid soils ($pH < 6.5$) occupy about 34% of the total cultivated area (Panda 1987) and are widely distributed in the Himalayan regions, the eastern and north eastern plains and states under varying climate and environmental conditions. The major areas covered by acid soils are (i) Laterites and latosolic soils, mixed red and black, red and yellow soils, (ii) Podzols and podsolised Himalayan and sub-Himalayan forest soils and (iii) Meadow soils, peaty soils and alluvial acid soils. Laterisation, podzolisation, intense leaching and accumulation of undecomposed organic matter under marshy conditions are the process contributing to acid soil development. The major areas covered by acid soils are (i) Laterities

Table 17.1. Major acid soil areas of India and their classification

Location	Chief characteristics	Soil taxonomy
Himalayas in U.P.	Precipitation is more	Haplumbrepts, Hapludalfs, Orthents, Fluvents, Ochrepts
Himalayas in U.P.	At higher altitudes	Mollic Hapludalfs, Mollic Hapludalfs, Mollic Umbrepts
Eastern Himalayan area	At higher altitudes	Udifluents, Udorthents, Ochrepts, Umbrepts
Laterites	At higher altitudes	Udalfs, Tropepts, Aquepts, Fluvents, Humults
Older laterites	Low rainfall regions	Ustalfs, Udalfs,
West Bengal, Orissa and Bihar	Laterites in the eastern plains	Udalfs, Aquepts, Fluvents
Southern peninsula	Red loamy soils	Udalfs, Fluvents, Orthents, Aquepts
Southern peninsula	Acid red and yellow soils	Dystrochrepts, Udifluents
Brahmaputra valley and Ganga basin	Acid red and yellow soils	Haplumbrepts, Udifluents, Psammments, Sulfaquepts
West Bengal	Costal plains and southern areas	Fluvents, Sulfaquepts

and various latosolic soils, e.g. ferruginous red soils, ferruginous gravelly red soils, mixed red and black, or red and yellow soils, (ii) Podzolic group – It includes many podsoles and podsolised Himalayan and sub-Himalayan forest soils and (iii) Meadow soils, peaty soils and alluvial acid soils. Acidic soils found in India may be grouped as in Table 17.1.

CHIEF CHARACTERISTICS OF ACID SOILS

- The acid soils have kaolinitic type of clay minerals, along with illite at some places.
- These are characterised by low cation exchange capacity, sandy loam to loam textural class, possess low content of organic matter, N and P.
- The colloidal material in acid soils has low dispersion and flocculates in a suspension.
- Their pH values range between 5 to 6 and generally % base saturation is less than 70. They are generally deficient in calcium and magnesium, the degree of saturation being usually 20–25%.
- The decomposition of humus by micro-organisms may lead to the formation of organic acids which contribute to the development of acid soils.
- Clay content and free iron oxides are the two dominant factors determining P fixing capacity of these soils.
- Many acid soils of ferruginous nature have a good store of K. Availability of K, however, depends on the mechanism of release in relation to K bearing minerals. The total variation in the K fixing capacity has been attributed mainly to the mineralogical composition. Red soils derived from the oldest geological formations are rich in sesquioxides but poor in K-bearing minerals.
- The micronutrient elements and their total contents reported in several acid soils showed a wide variation.
- In the acidic red soils the population of bacteria and actinomycetes have been estimated to be 1.6 and 1.0 million per gram. Fungal population, of 253,000 per gram in acid soils, was several times more than that of other soils. *Azotobacter* was found to be completely absent in the red acidic soils and nitrifying power of the soils was very low. The acidic lateritic soils had low nitrifying power, nitrogen fixing capacity and ammonifying power (Mandal, 1976).

ACTIVE AND RESERVE ACIDITY OF SOILS

Active acidity is the amount of hydrogen and aluminium ions present in the soil solution. The free H^+ ions create the active acidity. Reserve acidity is the amount of hydrogen and aluminium adsorbed by the clay and humus micelle. The exchangeable H^+ ions are the main source for the development of reserve acidity. Different forms of H^+ are in equilibrium with each other. It is therefore, necessary to neutralize reserve acidity of the soil to raise soil pH. Aluminium ions in soil solution are hydrolyzed to contribute to soil acidity as follows:

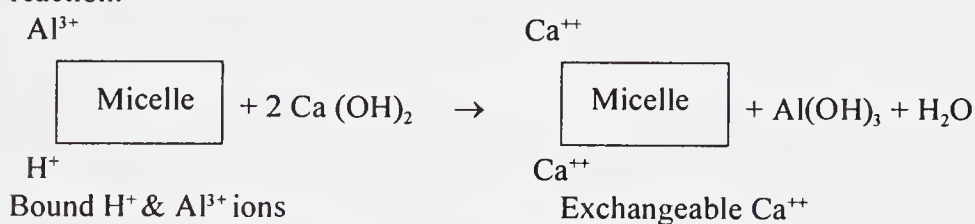


The H^+ ions thus released lower pH of the soil solution. An acid is substance that gives up protons. A base tends to accept protons. Aluminium ion is released

by hydrolysis of the primary minerals or comes into soil solution by exchange sites. Then each Al^{3+} ion combines with 3 OH^- ions and precipitates leaving three free H^+ ions, which reduce the pH value. In soils due to lack of basic cations, aluminium becomes soluble due to low pH. Aluminium is adsorbed on the permanent charge leaving the H^+ ions in solution.

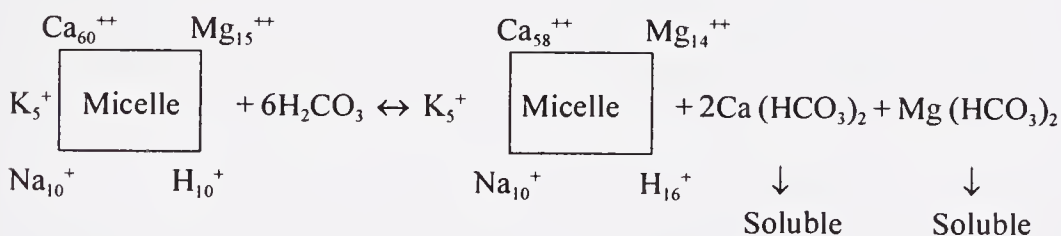
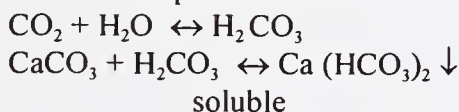


Adsorbed H^+ ions held in the exchangeable form are released in the soil solution and increases concentration of H^+ ions in the soil solution. Residual acidity may be 1000 times greater than the active acidity in a sandy soil and 50,000 times or so in a clayey soil. Application of $\text{Ca}(\text{OH})_2$ reduces acidity as shown in the following reaction:



CAUSES OF SOIL ACIDITY

Leaching due to heavy rainfall: Soil may turn acidic due to loss of calcium and magnesium salts in areas of high rainfall as in humid regions. It may be explained as follows: CO_2 is being continually formed because of respiration of plant roots and decomposition of organic matter. CO_2 reacts with water to form carbonic acid, which react with insoluble soil minerals rich in bases and converts them in their soluble forms. Soluble forms are lost through leaching. The following reactions show this phenomenon:

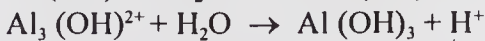
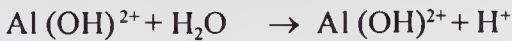


In the above equation, it is seen that Ca^{++} and Mg^{++} are lost as their soluble salts. K^+ , Na^+ and H^+ ions remain intact on the soil micelle.

Acidic parent material: Soils developed from acidic parent material such as granite, are acidic in nature.

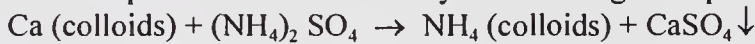
Presence of silicate clays: The silicate clay minerals contain a large amount of permanent charges while humus and allophanes have mainly pH-dependent charges. Aluminium hydroxyl ions are occupied in the interlayer space of the crystal units and are tightly adsorbed. Increasing pH results in the removal of these ions and the release of exchange sites. Thus with rise in pH, some hydrogen

and aluminium at low pH were bound by organic matter and 1:1 type clays are subjected to release as H^+ ions. Release of H^+ ions leads to development of soil acidity.

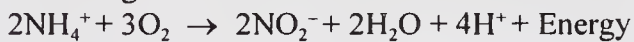


Microbiological action: i) Humus materials formed as a result of microbiological decomposition of organic matter contain different functional groups like carboxylic ($-COOH$), phenolic ($-OH$), enolic which are capable of dissociating hydrogen (H^+) ions. ii) Organic acids are being formed as a result of microbial activity. If these acids are not neutralized as in soils with low base content, soil acidity is developed.

Use of fertilizers: Application of ammonium sulfate or ammonium sulfate nitrate produces acidity. This is because ammonium ions replace calcium ions from the exchange complex and calcium sulfate thus formed may be leached. This is particularly true in soils containing less reserves of $CaCO_3$ as calcium ions thus lost are not replaced in soil solution by soil exchange complex

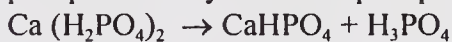


- Application of ammonium fertilizers: Ammonium ions will be attacked by micro-organisms and oxidized into nitrate ions as:



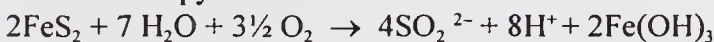
The oxidation of ammonium into nitrate (nitrification) occurs in two steps. In the first step, the bacterial conversion of ammonium into nitrite results in liberation of four protons, which may increase soil acidity.

- Application of mono phosphate fertilizers: Hydrolysis of calcium mono phosphate will yield ortho phosphoric acid.



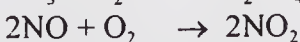
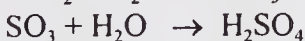
Being an acid, phosphoric acid will dissociate its proton in the soil solution and decreases soil pH.

- Oxidation of pyrite or sulfur:



It produces hydrogen ions ($8H^+$) and sulfur dioxide, which contributes to acid rain.

Acid rain: Carbon monoxide, nitrogen oxide and sulfur oxide gases are released into air by volcanoes. Also, the continuous production of unwanted gases, generated by combustion of fuel, disposal of refuse is of great concern. These gases are harmful to the environment, plant growth and human health. Nitrogen oxide gas may be harmful to the ozone layer of the stratosphere. Oxidation of sulfur dioxides and nitrogen oxide in the air and subsequent dissolution of the oxidation products produce sulfuric acid, nitric acid and their salts. The process of formation of acids can be illustrated as follows:



Sulfuric, nitric and nitrous acid are strong acids and will dissociate the proton in water droplets of rain. However, due to certain buffering capacity of soils the

effect of acidity of rain water is neutralized. The prolonged impact of acid rain can neutralize the buffering capacity of soils, which increases soil acidity. The sulfur in the coal is present as pyrite, FeS₂ and as organic sulfur. Upon burning the coal, the pyrite minerals are oxidized and sulfur dioxide is produced.

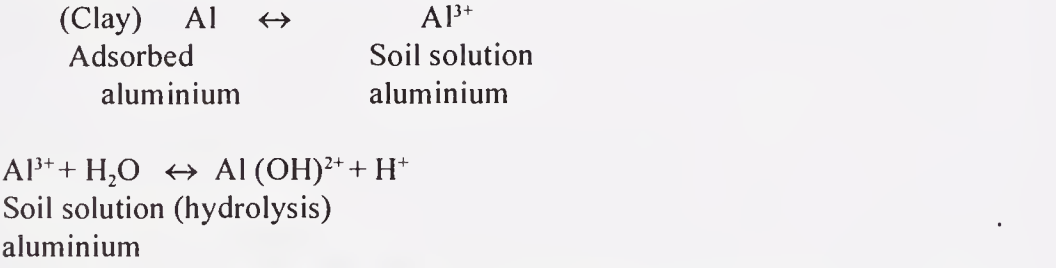
Effect of Aluminium Ions in Causing Soil Acidity

Under normal soil conditions in presence of water: Al³⁺ ions is surrounded by six molecules of water forming hexaqua aluminium compound Al(H₂O)₆³⁺. On hydrolysis, hydroxyl (OH⁻) ion is attached to the aluminium. Thus, aluminium becomes less positively charged. Different forms of aluminium can be :

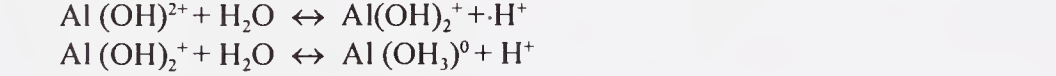
Stepwise hydrolysis		Dominant aluminium species	pH
Al(H ₂ O) ₆ ³⁺ + H ₂ O	↔	Al(H ₂ O) ₅ (OH) ²⁺ + H ₃ O ⁺	< 4.7
Al(H ₂ O) ₅ (OH) ²⁺ + H ₂ O	↔	Al(H ₂ O) ₄ (OH) ₂ ⁺ + H ₃ O ⁺	4.7-6.5
Al(H ₂ O) ₄ (OH) ₂ ⁺ + H ₂ O	↔	Al(H ₂ O) ₃ (OH) ₃ ⁰ + H ₃ O ⁺	6.5-8.0
Al(H ₂ O) ₃ (OH) ₃ ⁰ + H ₂ O	↔	Al(H ₂ O) ₂ (OH) ₄ ⁻ + H ₃ O ⁺	8.0-11.0

Thus aluminium in solution is pH dependent. Aluminium hydrolysis products can be readsorbed by clay minerals causing further hydrolysis with the release of H⁺ ions in the soil solution and thus develops soil acidity.

Under strongly acid soils: The adsorbed aluminium is in equilibrium with aluminium (H³⁺) ions in the soil solution. Aluminium ions in solution produces hydrogen (H⁺) ions through the process of clay hydrolysis,



Under moderately acid soils: At comparatively higher pH values, aluminium exists as aluminium hydroxy ions and on hydrolysis liberate hydrogen (H⁺) ions in the soil solution.



EFFECTS OF SOIL ACIDITY ON PLANTS

The main benefit of lime is through increased availability of nutrients other than calcium. Lime makes nutrients more available that are present. Acid loving plants are injured by the addition of lime. They are favoured by the increased availability of certain nutrients such as iron and manganese rather than by the high concentration of H⁺ ions at low pH. Potatoes grow well on soils high in lime. Also,

potatoes tolerate acid soils, but the scab organisms do not. Ammonium fertilizers are advantageous for potato susceptible to scab because of their acidifying effect.

Soil acidity may directly or indirectly cause damage to plants.

Direct Effects

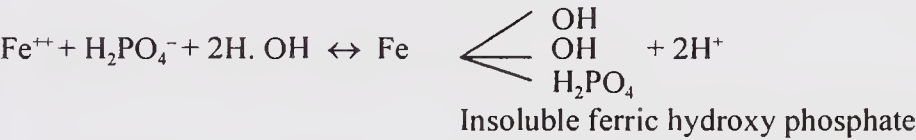
- H⁺ ions have toxic effect on root tissues and permeability of the plant membrane for cations by affecting enzymic changes. Enzymes are pH sensitive.
- H⁺ ions are detrimental to the growth of many bacteria.
- Excess Al³⁺ interferes with cell division in plant roots, inhibits nodule initiation, decreases root respiration, increase cell wall rigidity.
- Al³⁺ interferes with the uptake, transport and use of nutrients and water by plants.

Indirect Effects

It has been proved that the harmful effects of acidity are due to secondary causes.

Toxic Effects of Aluminium, Iron and Manganese: Acidic soils contain excessive amounts of aluminium, iron and manganese in a soluble form which are harmful for crop growth. Excess manganese accumulates in all tissues and interferes with their proper metabolism. Excess aluminium accumulates in the roots and reduces their power of translocating phosphates from the soil to the vascular system.

Phosphorus availability: Al⁺⁺⁺ reduces availability of phosphorus. Orthophosphate ions H₂PO₄⁻ are precipitated as insoluble hydroxy phosphates. It occurs as follows:



Availability of molybdenum: Acidity causes deficiency of molybdenum as it forms complexes with iron and aluminium compounds. Molybdenum is strongly adsorbed to iron and aluminium hydrous oxides.

Activity of soil organisms: Bacteria and actinomycetes cannot function properly in acidic range while fungi may work satisfactorily in acidic conditions. Activities of these soil organisms affect availability of plant nutrients, as these organisms are responsible for conversion of unavailable forms of nutrients to their available forms. When the soil becomes too acid, the soil fauna becomes very restricted. Earthworms die out.

LIMING

Raising the soil pH to a reaction near neutral or just above it is done through liming. Liming is the best measure to correct soil acidity. Liming means adding to the soil any compound containing calcium or calcium plus magnesium that is capable of reducing the acidity of the soil. Lime can be applied through several liming materials such as calcic limestone (CaCO₃); dolomite limestone

($\text{CaCO}_3, \text{MgCO}_3$), quicklime (CaO), hydrated or slaked lime $\text{Ca}(\text{OH})_2$ and miscellaneous sources like woodash and pressmud.

A satisfactory material for raising pH should have the following characteristics:

- It should have a mild alkalizing effect. The ideal liming material should have action mild enough so that it causes no harm even if an overdose is applied.
- It should have a desirable proportion of cations, mostly calcium or magnesium.
- It should have a favourable effect on soil structure.
- It should not be too expensive.

Reaction of Liming Material in Soil

When liming materials are added to the soil, the calcium and magnesium compounds react with carbon dioxide and the acid colloidal complex. Following reactions show reaction with CO_2 , resulting in the formation of bicarbonates.

- $\text{CaO} + \text{H}_2\text{O} + 2\text{CO}_2 \rightarrow \text{Ca}(\text{HCO}_3)_2 \downarrow$
- $\text{Ca}(\text{OH})_2 + 2\text{CO}_2 \rightarrow \text{Ca}(\text{HCO}_3)_2 \downarrow$
- $\text{CaCO}_3 + \text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{Ca}(\text{HCO}_3)_2 \downarrow$

These liming materials replace hydrogen and aluminium ions tightly held on the acid colloidal complex. The adsorption of calcium replacing hydrogen ions of colloidal complex may be indicated as follows:

- $\text{H}^+ \boxed{\text{Micelle}} + \text{Ca}(\text{OH})_2 \leftrightarrow \text{Ca}^{2+} \boxed{\text{Micelle}} + 2\text{H}_2\text{O}^+$
- $\text{H}^+ \boxed{\text{Micelle}} + \text{Ca}(\text{HCO}_3)_2 \leftrightarrow \text{Ca}^{2+} \boxed{\text{Micelle}} + 2\text{H}_2\text{O} + 2\text{CO}_2$
- $\text{H}^+ \boxed{\text{Micelle}} + \text{CaCO}_3 \leftrightarrow \text{Ca}^{2+} \boxed{\text{Micelle}} + 2\text{H}_2\text{O} + \text{CO}_2$

CO_2 is freely evolved which helps in the formation of $\text{Ca}(\text{HCO}_3)_2$. Adsorption of Ca^{++} and Mg^{++} raises base saturation of the colloidal complex which, results in an increase in soil Al^{+++} pH.

- $3\text{H}^+ \boxed{\text{Micelle}} + \text{H}_2\text{O} + 2\text{CaO} \rightarrow 2\text{Ca}^{2+} \boxed{\text{Micelle}} \text{Al}^{+++} + \text{Al}(\text{OH})_3$
- $3\text{H}^+ \boxed{\text{Micelle}} \text{Al}^{3+} + 2\text{Ca}(\text{OH})_2 \rightarrow 2\text{Ca}^{2+} \boxed{\text{Micelle}} + \text{Al}(\text{OH})_3 + \text{H}_3\text{O}^+$
- $3\text{H}^+ \boxed{\text{Micelle}} + 2\text{CaSiO}_3 + 3\text{H}_2\text{O} \rightarrow 2\text{Ca}^{2+} \boxed{\text{Micelle}} + 2\text{H}_2\text{SiO}_3 + \text{Al}(\text{OH})_3$
Basic slag

Other Liming Materials and their Action

The carbonates, oxides, hydroxides and silicates of calcium and magnesium are used as liming material.

- Carbonates of lime: Calcic limestone (CaCO_3), dolomite limestone, ($\text{Ca}, \text{Mg}(\text{CO}_3)_2$)
- Oxides of lime: Quick limes CaO . This is produced by heating limestone and

dolomite as follows:



- Hydroxides of lime:
 $\text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2$
- Chalk (CaCO_3) and marl (CaCO_3): When soils are high in lime, water is rich in lime by precipitation through drainage water.
- Blast furnace slag (CaSiO_3 and CaSiO_4), a by-product of iron industry. This product is called basic slag and is used for its high phosphorus content.
- Other liming materials: Coral shell, wood ashes, by-product lime resulting from paper mills, sugarbeet plants, flyash from coal burning plants are considered as liming materials and used for amelioration of soil acidity.

Gypsum, though Containing Calcium Cannot be Considered as a Liming Material Since:

- When applied to soil, it dissociates into calcium (Ca^{2+}) and sulphate (SO_4^{2-}) ions. Sulfate reacts with soil moisture and produces sulfuric acid.
 $\text{SO}_4^{2-} + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4$
- Ca^{2+} in the gypsum after dissociation will result in replacement of adsorbed aluminium (Al^{3+}) which results in further lowering of soil pH.

EFFICIENCY OF LIMING MATERIAL

It depends on Following Factors

- Calcium carbonate equivalent of liming material: Pure calcium carbonate is taken as the standard against which liming materials are measured. The neutralizing value of CaCO_3 is considered to be 100%. Pure CaCO_3 has a molecular weight of 100 (Table 17.2).
- Purity of liming material: Purity will increase its efficiency.
- Fineness of the liming material: The finer the material, more rapidly it dissolves into solution and more effective it becomes. Material passing through a 60 mesh is more effective.

Management of Acid Soils of India

- Application of lime has been found very effective in the laterite and acidic red soils in increasing production of rice. Since rice has a greater degree of tolerance for acidity, attempts to get higher production of rice in acid soils have not been very successful. However, at very low pH (below 5) some

Table 17.2. Neutralizing value of commonly used liming materials

Liming material	Chemical composition	Neutralizing value
Limestone	CaCO_3	100 %
Burnt lime	CaO	179 %
Slaked lime	Ca(OH)_2	136 %
Dolomite	$\text{CaMg(CO}_3)_2$	109 %

response of paddy to lime has been obtained.

- The crops that have responded well to lime are legumes, cotton, maize, sorghum, wheat and linseed.
- Good result from lime application have been obtained on *Phaseolus mungo*, jute and mustard in Assam, jute in West Bengal, horsegram in Orissa, paddy and groundnut in Karnataka, paddy and cotton in Tamil Nadu, wheat and maize in Himachal Pradesh and paddy in Kerala.
- Extensive investigations on the liming of acidic red loam soils of Chotanagpur have been conducted. Lime application to the soil has caused 100 to 600 % increases in the yields of cereals, pulses, cotton, oilseeds, fodder crops and vegetables.
- Response to fertilizer also increased considerably, in the presence of lime.

On the basis of responses to liming, three groups of upland crops, viz. high response group (*arhar*, soybean, cotton, etc.), medium response group (gram, lentil, peas, maize, sorghum etc.), low or no response group (paddy, small millets, mustard etc.) have been recognised (Mandal, 1976).

METHOD AND TIME OF APPLICATION OF LIMING MATERIAL

- The best results are obtained from liming when there is a close contact between the particles of liming material and the soil. Surface application of lime without proper mixing in the soil are not effective in correcting subsoil acidity.
- Lime should be spread evenly over the entire field and then mixed well into the soil. After lime is spread, plowing or discing mixes lime into the soil. If it is not mixed into the soil, the lime will move slowly into the soil.
- Lime should not be applied with some forms of nitrogen fertilizer because it can cause nitrogen losses. It takes a few months for the lime to thoroughly react in soil.
- When large quantities of lime are to be applied, it is advisable to apply small quantities two or three times rather than giving one heavy application. Such applications are needed on strongly acid soils.

LIME REQUIREMENT OF ACID SOIL

The amount of CaCO_3 or any other liming material, required to raise the pH of the soil to a desired value under field conditions is known as lime requirement. It is expressed in kg /ha. The amount of lime to be applied depends on

Efficiency of the liming material: It includes calcium carbonate equivalent, purity and fineness of liming material.

The lime requirement of the crop: Pulses and legumes require large quantities of lime.

Soil pH: It can be used as an index of the differing lime needs of various crops.

Percent exchangeable aluminium: It controls active soil acidity.

Soil series: The lime requirement can be predicted accurately when the soil series is known. The series defines texture, structure, minerology and other root

zone characteristics such as humus content and permeability, which may affect lime response.

Buffering capacity of soil: The relationships of texture, cation exchange capacity and buffering capacity should also be known. If more clay and organic matter is there in a soil, more lime is needed to change the pH. If soils are high in organic matter, more lime is required to bring the same change in pH than in a similar soil that is low in humus.

Type of clay: The relative lime requirement of the principal clay minerals are in the order, Vermiculite > Montmorillonite > Illite > Kaolinite > Sesquioxides.

Desired pH level: As the desired pH increases in value closer to neutrality, the amount of lime required to effect the same relative pH change becomes greater.

Determining the Lime Requirement of Soils

Titrating the soil with an acid or a base: HCl and $\text{Ca}(\text{OH})_2$ are usually used as acid and base respectively. pH is determined after equilibrating the soil with known amount of acid or base. The increase or decrease in pH values is reported. From these data it is simple to determine the amount of lime to be added.

Use of buffer solution: When an acid soil is added to a buffered solution, the buffer pH is depressed. This is proportional to the buffering capacity and pH of the soil. By calibrating pH changes in the buffered solution, the amount of lime required to increase pH to desired level can be calculated.

The current emphasis is on determination of Al^{3+} saturation and recommendation of lime based on the neutralization of exchangeable Al^{3+} . In acid soils exchangeable Al^{3+} is generally considered to be the predominant cation as determined by extraction with a neutral salt solution, like KCl. Lime rates based on neutralization of exchangeable Al^{3+} have been found to be adequate for optimum yields of many crops. Lime application based on KCl- Al^{3+} gave significantly higher dry matter yield of maize (Prabhuraj and Murthy, 1994). They further indicated that the major contributing factors for producing different kinds of acidities are exchangeable Al^{3+} , exchangeable H^+ and functional groups of soil humus.

EFFECT OF LIMING MATERIALS ON SOILS AND PLANTS

Effect of Liming on Soils

Neutralises soil acidity: Lime neutralises soil acidity. The addition of lime raises soil pH thus eliminating toxic effects of soluble aluminium. The adsorbed aluminium ions are replaced with calcium. H^+ ions are neutralized by liming materials.

Bacterial activity: Activity of beneficial soil bacteria is encouraged by adequate supplies of lime in the soil. Thus liming increases decomposition of organic matter and promotes nitrification by increasing microbial activity.

Neutralises toxic effects of iron and manganese: It reduces toxicity of iron and manganese as they are converted into their insoluble hydroxides (Fe and Mn are highly soluble at low pH and thus toxic).

Availability of phosphorus: Lime makes phosphorus more available in acidic soils. This is explained as follows. In acidic soils, iron and aluminium combine

with fertilizer phosphate to make insoluble compounds that is, iron and aluminium phosphates. Since liming reduces the solubility of iron and aluminium, less of the added phosphorus will combine with iron and aluminium to form their insoluble phosphates. Liming acid soils will precipitate Fe and Al as $\text{Fe}(\text{OH})_3$ and $\text{Al}(\text{OH})_3$, thus increasing plant available P.

Micronutrient availability: The addition of lime reduces the concentration of micronutrients. Soil pH values of 5.8 or 6 are sufficient to minimize toxicity. At this pH value micronutrients available are enough to meet plant requirements. Molybdenum availability to crops is improved by liming because of improved solubility of Mo at higher pH.

Nitrification and N fixation: Most of the organisms responsible for the conversion of NH_4^+ to NO_3^- require large amounts of Ca; therefore, liming to a pH of 5.5 to 6.5 enhances nitrification. Activity of some Rhizobia species is restricted at low pH value; thus liming will increase the growth of legumes because of increased nitrogen fixation.

Soil physical condition: Liming improves soil physical condition. Decreasing bulk density and increasing infiltration capacity and percolation of water when lime is applied over a period of years reflects this.

Effect of Liming on Plants

- Lime makes potassium more efficient in plant nutrition. When lime is abundant, plant takes more of calcium and less of potassium even if potassium is abundant in soils. Since calcium is usually more deficient in plant content (including fodder) than potassium, this is desirable. Thus, lime reduces excessive uptake of potassium because plants have a tendency to absorb more of it than they need.
- Lime increases the availability of nitrogen by enhancing the decomposition of organic matter through greater microbial activity at higher pH.
- Liming reduces solubility and plant uptake of heavy metals like cadmium, copper, lead, nickel, zinc which are toxic for plants if present in higher concentrations.

Mandal, 1976 observed that the beneficial effect of liming on maize in an acid soil (pH 5.7) lasted for 5 years. Application of lime made every year or every season gave no additional advantage. The lime requirement of an acidic red soil of loam texture and pH 5.5 has been estimated as 37.5 quintals per hectare.

Over Liming

- When large amounts of lime are applied to sandy soils low in humus (in soils possessing a poor buffering capacity), injury to plant growth may occur.
- Lime requirement of crops differ. Barley, Cotton, Sugarbeets have the highest; maize, wheat, tobacco have a medium requirement; potato, rice have the lowest requirement. Over liming to crops having medium to low requirement of lime may cause toxicity.
- Over liming may cause following harmful effects:
 - Boron deficiency.
 - Deficiencies of iron, manganese, copper and zinc by decreasing their solubility.

- Reducing the availability of phosphorus. Phosphorus availability is maximum between pH range of 5.5 to 6.5 (like HPO_4^{2-} and H_2PO_4^-). Further increasing pH results in formation of its unavailable forms (like PO_4^{3-}).

Correction of over liming: Application of manures, green manuring, composts, phosphate fertilizers and a mixture of micronutrients may reduce lime injury.

References and Suggested Readings

- Mandal, S.C. (1976) Acid Soils of India and their management. (In) *Acid Soils of India – their genesis characteristics and management*, Bull. No. 11, ISSS, New Delhi.
- Panda, N. (1987). *Journal of Indian Society of Soil Science* **35** : 568.
- Prabhuraj, D.K. and Murthy, S.P. (1994). *Journal of Indian Society of Soil Science* **42** : 455–9.
- Mandal, S.C., Sinha, N.K. and Sinha, H. (1975). *Acid Soils of India and Liming*, ICAR, New Delhi.
- Whither Soil Research (1982). *12th International Congress of Soil Science*. New Delhi. Panel Discussion Papers, 8–16 February 1982.

QUESTIONS

Q. 1. Fill in the blanks

- Soils developed from acidic parent material are _____ in nature
- Aluminium ions in solution produces hydrogen (H^+) ions through the process of _____.
- _____ plants are injured by the addition of lime
- _____ is taken as the standard against which liming materials are measured
- The neutralizing value of CaCO_3 is considered to be _____ per cent
- Nitrification is enhanced by liming to a pH of _____
- Lime reduces excessive uptake of _____

Answers

- (i) acidic (ii) hydrolysis (iii) acid loving (iv) pure CaCO_3 (v) 100 (vi) 5.5 to 6.5 (vii) potassium

Q. 2. Choose the correct answer

- In acidic soils, the concentration of Al^{3+} ions increased / decreased
- An acid is a substance that give up / accept protons
- Excess aluminium accumulates in the roots and reduces / increases their power of translocating phosphates from the soil
- Acidic conditions are unfavorable / favorable for earthworms in soil
- Lime may not be applied / may be applied along with nitrogenous fertilizers
- Liming reduces / increases plant uptake of heavy metals

Answers

- (i) increased (ii) give up (iii) reduces (iv) unfavorable (v) may not be applied
(vi) reduces

Q. 3. Define the following

- (i) liming (ii) Lime requirement (iii) Calcium carbonate equivalent

Q.4. Differentiate between the following

- (i) Active and reserve acidity of soil (ii) Acid and base (iii) Lime requirements of a heavy textured soil and a coarse textured soil

Q. 5. Write short notes on the following

- i) Hexaquoaluminium
- ii) Acid loving plants
- iii) Satisfactory liming material
- iv) Method and time of application of lime
- v) Effect of liming on plants
- vi) Over liming (vii) Methods of determination of lime requirement of soils

Q. 6. Give comments on the following statements

- i) Acidic soils are developed in areas of high rainfall
- ii) It is necessary to neutralize reserve acidity of the soil to raise soil pH
- iii) Aluminium ion causes soil acidity
- iv) Application of $\text{Ca}(\text{OH})_2$ reduces acidity
- v) Application of ammonium sulfate produces acidity
- vi) Ammonium fertilizers are advantageous in case of potato scab
- vii) Soil acidity reduces availability of phosphorus
- viii) Gypsum cannot be considered a liming material
- ix) The lime requirement can be predicted accurately when the soil series is known
- x) Lime requirement also depends on the type of clay minerals dominant in the soil
- xi) Liming increases the growth of legumes
- xii) Molybdenum availability is improved by liming
- xiii) Liming improves physical condition of the soil
- xiv) Higher production of rice through application of lime on acid soils has not been very successful

Q. 7. Answer the following in brief

- i) What is the role of CO_2 in leaching of bases. Give equations.
- ii) What is the role of soil organisms in developing soil acidity
- iii) What are different forms of aluminium ion under different pH values. How does aluminium ion cause acidity under varying pH levels under normal conditions in presence of water
- iv) What are the direct effect of acidity on plants
- vi) Enlist factors controlling amount of lime to be applied in a soil
- vii) What practices should be adopted to reduce lime injury.

Q. 8. Answer the following in detail

- i) Explain factors that cause soil acidity
- ii) Application of fertilizers causes acidity in soil. Support your answer with examples.
- iii) Illustrate through equations the formation of acids through various atmospheric gases
- iv) What is the effect of soil acidity on the availability of phosphorus and molybdenum
- v) Explain the mechanism of adsorption of Ca^{++} and Mg^{++} (through addition of lime of materials) on the colloidal complex.



Chemistry and Availability of Major Nutrients

Nitrogen

Nitrogen occurs in soil in both cationic (NH_4^+) and anionic (NO_3^- , NO_2^-) forms, the greater part occurs in organic forms. NH_4^+ fixed on the cation exchange sites, are tightly bound by clay and are slowly available to plants. The available nitrate and ammonium form is only 1–2% of the total soil nitrogen. Nitrate is highly mobile. Nitrogen availability depends upon the rate at which organic nitrogen is converted to inorganic nitrogen (mineralization). Most soil nitrogen is unavailable to plants. The amount in available forms is small and crops withdraw a large amount of nitrogen. Two forms of nitrogen available to plants are nitrate (NO_3^-) and ammonium (NH_4^+). Roots can absorb both of these forms, although many species preferentially absorb nitrate-nitrogen over ammonium-nitrogen. Nitrogen performs important functions in plant growth.

- Nitrogen is an important component of chlorophyll, enzymes, amino acids and proteins.
- Nitrogen stimulates root growth, development and uptake of other cations.
- Nitrogen encourages vegetative growth.

Nitrogen deficiency is first observed when older leaves of plants turn yellow. Toxicity of nitrogen leads to (i) excess vegetative growth (ii) lodging (iii) delayed maturity (iv) plants become susceptible to diseases and insect pests.

NITROGEN CYCLE

The primary source of nitrogen is the atmosphere. Soil nitrogen comes from living things. Sedimentary rocks contain more nitrogen as compared to igneous rocks.

Nitrogen passes repeatedly through its various forms as it moves from the soil into the bodies of living organisms and back again. Fig. 18.1 illustrates the complex cycle in which nitrogen is involved. The nitrogen in soils is derived from fertilisers, crop residues, organic manure, ammonium and nitrate salts brought down by precipitation. Atmospheric nitrogen is also fixed by certain organisms. Nitrogen may be lost through following ways:

(i). Denitrification; (ii). Immobilization; (iii) Leaching of mineral nitrogen (NO_3^- and NH_4^+) beyond the root zone of the plant; (iv). Decomposition of organic matter low in nitrogen by soil organism and subsequent absorption of N by these organisms contributes to the unavailability of nitrogen for plant uptake; (v).

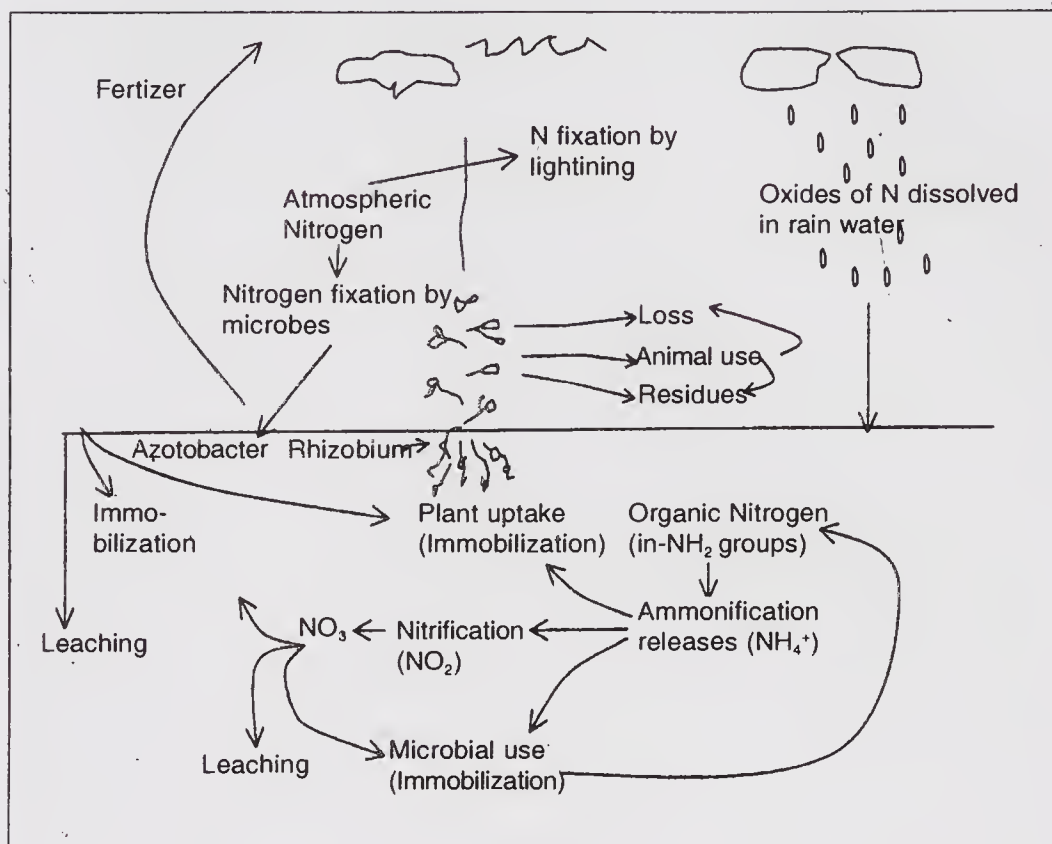


Fig. 18.1. The Nitrogen Cycle

Under conditions of low water availability and high pH ammonium (NH_4^+) is converted to volatile ammonia (NH_3). The gaseous ammonia is lost into the atmosphere vi). Fertiliser loss by runoff is another critical source of nitrogen loss.

Nitrogen Transformation in Soils

The cycling of N in the soil - plant - atmosphere system involves many transformations of N between inorganic and organic forms. Nitrogen is subjected to amino compounds (R-NH_2 , R represents the part of the organic molecule with which amino group (NH_2) is associated), then to ammonium (NH_4^+) ion and nitrate (NO_3^-). Ammonium nitrogen is often converted to nitrate-nitrogen by micro-organisms before absorption through a process called nitrification.

Nitrogen Mineralization

The conversion of organic N to NH_4^+ and NO_3^- is known as nitrogen mineralization. Mineralization of organic N involves two reactions, amination and ammonification, which occur through the activity of heterotrophic micro-organisms. The enzymatic process may be indicated as follows:

Mineralization

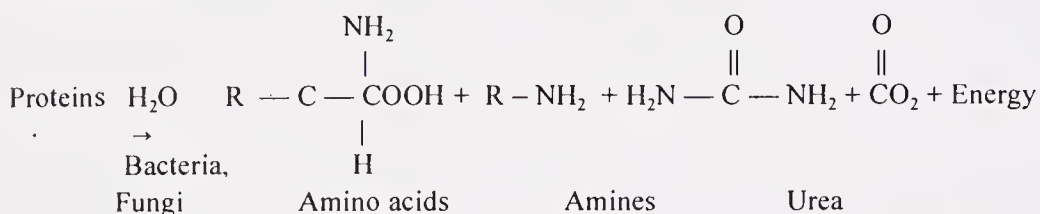
RNH_2	$+\text{H}_2\text{O}$		$+\text{O}_2$			$+\text{O}$	
	$\rightleftharpoons$		$\rightleftharpoons$			$\rightleftharpoons$	
	$-\text{H}_2\text{O}$	$\text{ROH} + \text{NH}_4$	$-\text{O}_2$	NO_2^-	$+4\text{H}$	O	NO_3^-

Immobilization

R represents the part of the organic molecule with which amino group (NH_2) is associated.

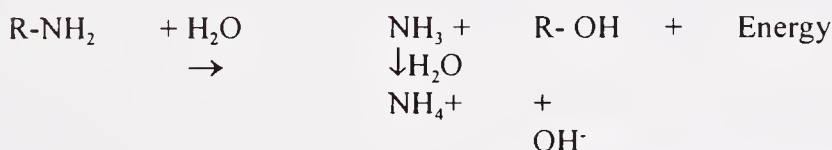
Aminisation

The decomposition of proteins into amines, amino acids and urea is known as aminisation.



Ammonification

The step, in which, the amines and amino acids produced by aminisation of organic N are decomposed by other heterotrophs, with the release of NH_4^+ , is termed ammonification.

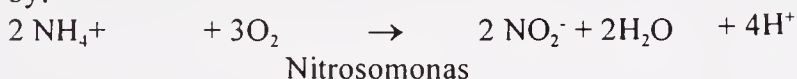


Nitrogen Immobilization

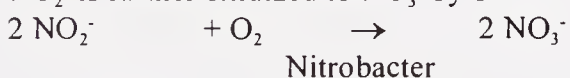
Immobilization is the process in which available forms of inorganic nitrogen ($\text{NO}_3^- - \text{NH}_4^+$) are converted to unavailable organic nitrogen. Immobilisation includes assimilation and protein production so those inorganic ions are made into building block of large organic molecules.

Nitrification

Nitrification is a process in which NH_4^+ released during mineralization of organic N is converted to NO_3^- . It is a two step process in which NH_4^+ is converted first to NO_2^- and then to NO_3^- . Biological oxidation of NH_4^+ to NO_2^- is represented by:



NO_2^- is further oxidized to NO_3^- by bacteria



Modification of NH_4^+ to NO_3^- depends on the temperature of the soil. Transformation proceeds more quickly under warmer soil temperature (about 50°F). Nitrification occurs most efficiently when soil pH is between 5.5–6.5. Nitrification can be completed within 2–4 weeks.

The reaction rates associated with nitrification in most well - drained soils are NO_2^- to $\text{NO}_3^- > \text{NH}_4^+$ to NO_2^- . As a result, NO_2^- generally does not accumulate in soils, which is fortunate, since NO_2^- is toxic to plant roots.

Losses from the Nitrogen Cycle

Nitrogen supply would not be a problem if there were no losses from the mineralization – immobilization cycle. The various losses include.

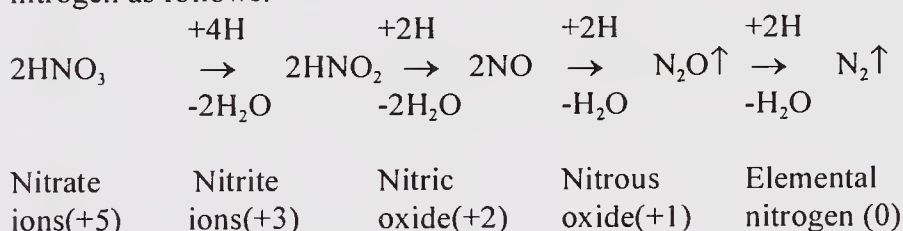
Crop harvest: One of the biggest losses is from crop harvest. Large amounts of nitrogen are consumed by the field crops etc.

Erosion losses: Every ton of soil lost from field carries nitrogen with it. A 10 tonnes loss of soil containing 4% organic matter would amount to 20 kg of nitrogen.

Leaching losses: Nitrate nitrogen is easily leached from permeable soil. Leaching periodically removes most of the nitrate nitrogen from the profiles of permeable soils in humid regions. Among the several factors that affect leaching losses are (a) the rate of nitrification (and fertilisation), (b) the amount of rain, (c) the permeability and water holding capacity of the soil, and (d) the crop growing on the soil. The leaching losses can be reduced if ammonium form of nitrogen is applied when the top soil temperature is below 5° C.

Volatilization: There are several volatile forms of nitrogen (N₂), ammonia (NH₃), and the various oxides of nitrogen (NO, N₂O, etc.).

Denitrification: Denitrification, is a process which involves the bacterial conversion of nitrate nitrogen (NO₃⁻) to nitrite (NO₂⁻) to nitric oxide (NO), nitrous oxide (N₂O) or nitrogen gas (N₂) which is subsequently lost from the soil as it is released into the atmosphere. The most probable biochemical pathway leading to these losses involves the reduction of 5-valent nitrogen to the zero-valent elemental nitrogen as follows:



In these reactions a specific enzyme reductase is important. Only a few, particular kind of facultative aerobic bacteria are responsible for denitrification, and the active species belongs to the genera *Pseudomonas*, *Bacillus*, and *Paracoccus*. Several autotrophs involved in denitrification include *Thiobacillus denitrificans* and *T.thioparus*.

Denitrification losses are more where drainage is restricted or under flooded conditions. The losses can be reduced under anaerobic condition by preventing the formation of nitrates. In such cases, fertiliser use efficiency can be increased by deep placement of the fertilisers. Denitrification losses can be reduced considerably by improved soil drainage.

FATE OF NITROGENOUS AND PHOSPHATIC COMPOUNDS

Crop plants recover only 25-70% of N and 5-30% of P fertilizers. The fertilizer nutrients can end up in the soil, waterways and atmosphere (Table 18.1).

Increasing Fertilizer Use Efficiency (Nitrogen)

Drip irrigation system and placement of fertilizer: Malik *et al.* (1994) studied

Table 18.1, Fate of fertilizer N and P after application to crops*

	N	(% of nutrient applied)	P
Crop removal	25–70		5–30
Retained in soil	0–30		70–95
Leaching and runoff	0–30		0–10
Volatilisation	0–40		
Denitrification	0–30		

* Anon (1983)

the effect of urea application through drip irrigation system on nitrate distribution in loamy sand soils on pea yield. They found that (a) The maximum fertilizer use efficiency may be obtained by more uniform distribution and maximum utilization of fertilizer by the crop as it remained within the reach of effective root zone system, (b) Drip system of irrigation can be very effective and efficient method of water and fertilizer application; especially, on light textured soils and under water scarcity areas and (c) At maximum growth stage, $\text{NO}_3\text{-N}$ content in soil profiles was maximum with weekly irrigation + 25 kg N/ha through drip.

Application of sludge: Soni *et al* (1994) found that the absolute amounts of N mineralized increased significantly with increasing levels of sludge application at each incubation period (Table 18.2).

Use of urea super granules with deep placement: Das and Singh (1994) observed that grain yield and nitrogen use efficiency by rice (var. Jaya) was more when urea super granules (USG) were deep placed as compared with urea super granules broadcast and incorporated and prilled urea applied in three splits in an Aquic Hapludoll (Table 18.3).

Influence of heavy metals: Gupta and Chaudhry (1994) studied the influence

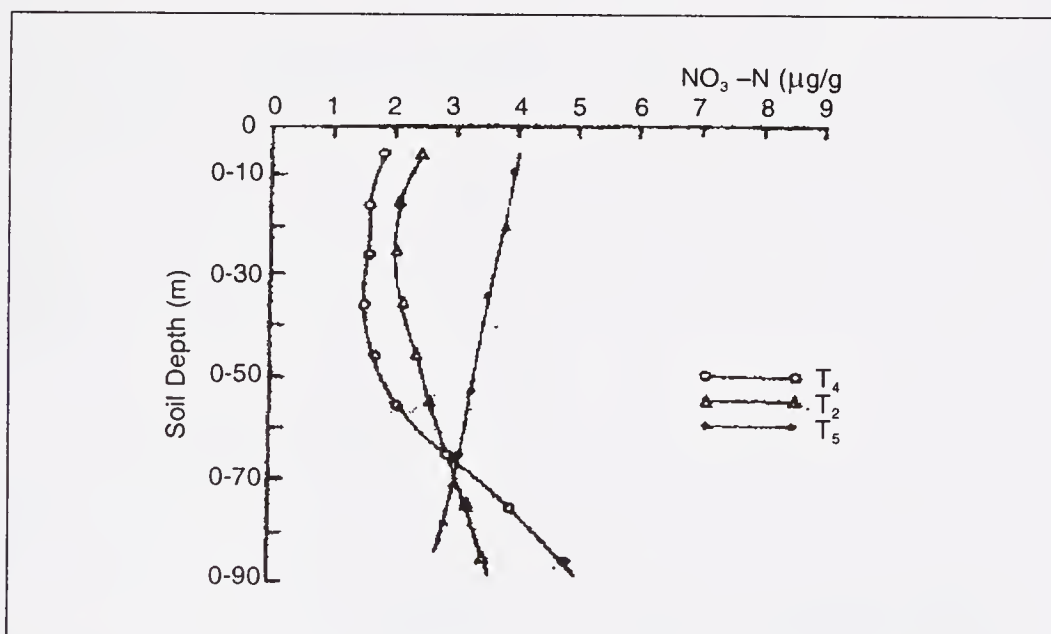


Fig. 18.2. Depthwise distribution of nitrate at flowering stage of pea

Table 18.2. Effect of sludge on mineralized N during six weeks of incubation period

Sludge level	Incubation periods (weeks)					
	1	2	3	4	5	6
	<i>N mineralized (mg/kg)</i>					
0.0	6.8	11.0	14.5	17.0	18.8	19.5
0.5	11.3	20.0	25.0	28.8	31.0	33.0
1.0	14.8	24.3	31.3	37.5	41.0	43.3
2.0	16.8	28.8	36.5	43.0	46.8	50.0
4.0	19.8	33.3	40.8	46.8	51.5	55.3
CD (P=0.05)	0.8	1.2	1.4	1.6	1.7	1.7

Source: Soni *et al.* (1994)

of heavy metals and temperature on urea transformation in a Typic Ustochrept. They found that increasing the level of Ni, Zn and Hg from 200 to 400 mg kg⁻¹ soil decreased nitrate concentration significantly. This inhibitory effect of different metals may be due to the toxic effect to the activity of nitrifiers, which are sensitive to various metal ions (Dhull *et al.* 1989).

Increasing Fertilizer Use Efficiency (Phosphorus)

Incorporation of FYM

Phosphorus application increased the bulb yield of onion with the successive increase in the level of P. The incorporation of farmyard manure at the rate of 10 tonnes/ha, increased the bulb yield of onion (Table 18.4). farmyard manure mobilises both native and applied P.

Fate of Nitrogenous Compounds

Fate of Ammonium Nitrogen

- Considerable amounts are appropriated by organisms capable of using this type of compound, for example mycorrhizal fungi are able to absorb ammoniacal nitrogen and pass it on in some form to their host.
- Higher plants are able to use this form of nitrogen, often very readily although they seem to grow better if some nitrate nitrogen is also available. Ammonium-nitrogen is not as readily utilised by most plants as nitrate-nitrogen.
- Ammonium ions are subject to fixation by vermiculite, smectites and organic matter.

Table 18.3. Nitrogen levels needed for optimum and maximum grain yield of rice

Nitrogen sources	Nitrogen levels (kg/ha) needed for	
	Optimum yield	Maximum yield
Urea splits	128	142
USG – Broadcast	96	104
USG – Deep placed	95	104

Source: Das and Singh (1994).

Table 18.4. Effect on the bulb yield of onion

Levels of P (kg P ₂ O ₅ /ha)	Onion bulb yield (q/ha)		
	No-FYM	FYM	Mean
P ₀	27.25	30.25	28.90
P ₃₀	39.33	50.55	44.94
P ₆₀	54.21	64.16	59.19
P ₉₀	65.49	78.05	71.77
P ₁₂₀	80.44	82.00	81.22
Mean	53.34	61.06	
CD (P=0.05) For P: 5.04, For FYM : 7.98, For P × FYM : 11.27			

Source: Sharma and Raina (1994)

- When plant and animal synthesis are temporarily satisfied, the remaining ammonium nitrogen may be readily oxidised by certain special bacteria (converts to nitrites and nitrates) which uses it not only as a source of nitrogen but also as a source of energy.
- Some ammonia may be lost into the atmosphere.

Fate of Nitrate Nitrogen

The nitrate nitrogen of the soil whether added as fertilizers or formed by nitrification (i) may be incorporated and assimilated into higher plants. Both plants and soil micro-organisms readily assimilate nitrate nitrogen, (ii) May be lost in drainage, or escape in a gaseous condition. Since, nitrate ions are negatively charged they cannot be adsorbed by the negatively charged colloids that dominate in soils. Consequently, they are subject to ready leaching and move downward with water. Nitrate nitrogen has a greater propensity towards leaching as compared to ammonium nitrogen.

Fate of Phosphate Compounds

Fertiliser P applied to tropical and subtropical soils undergoes dynamic change. This is dependent on the physico-chemical properties of each type of the soil (Fig. 18.3).

- The water-soluble P is slowly reverted to insoluble form. It depends on the activity of Fe, Al and Ca in soil. Most of the phosphorous present in soils is not readily available to plants.
- The various P fractions attain equilibrium with water soluble P in soil solution. When soluble fertiliser salts of this element are supplied to soils their phosphorus is often fixed or rendered insoluble or unavailable to higher plants, even under the most ideal field conditions. Also, phosphorous is only sparingly removed by leaching, The removal of phosphorous from soils by crops, however, is low as compared to that of nitrogen and potassium.
- P fixing capacity of the soil governs the availability of applied fertiliser P to plants.
- The plants are able to utilise P from different soil P fractions to varying degrees.
- Surface runoff of phosphates either as such or with soil erosion, which is

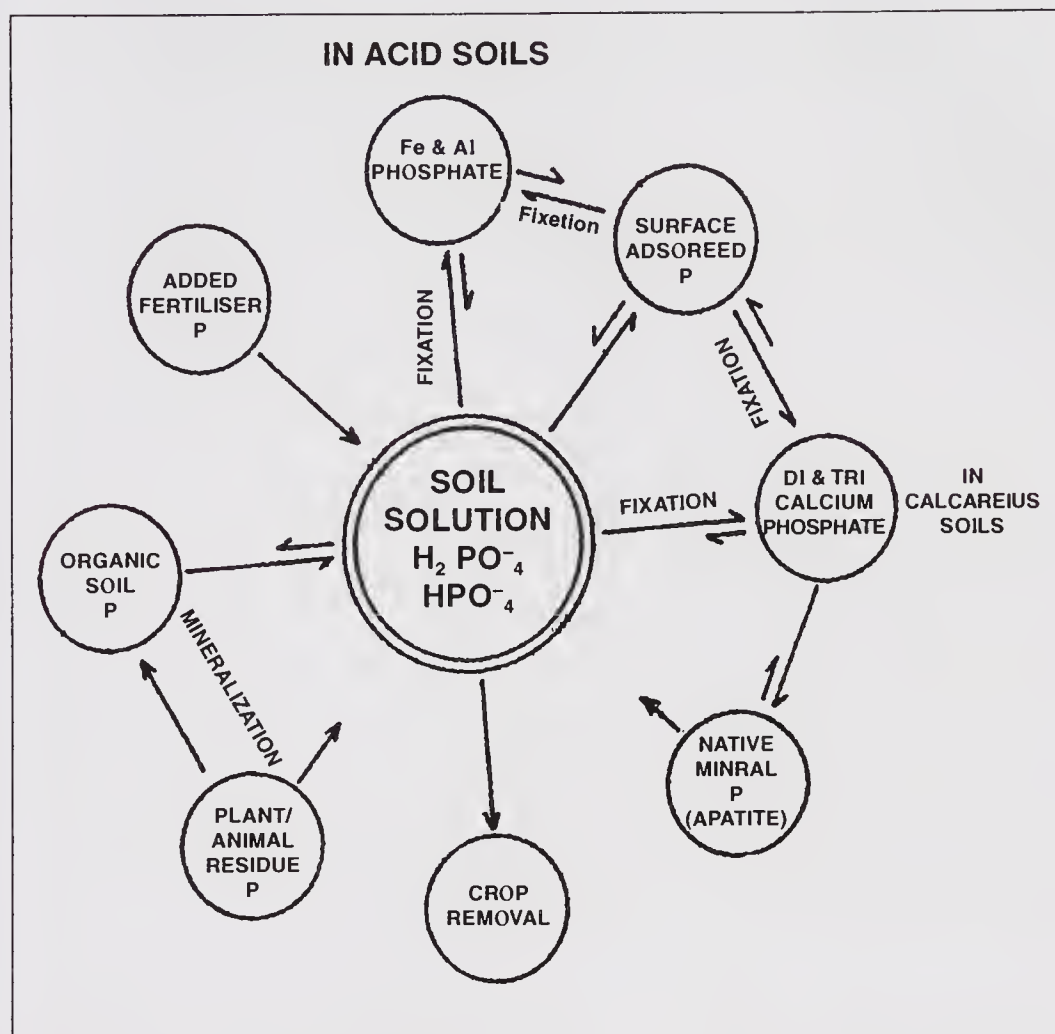


Fig. 18.3 Equilibrium relations among soil solution P and the various fractions of the element in soil. FAO (1980)

carried, with surface water leads to eutrophication. A concentration of 0.05 mg kg^{-1} P supports abundant growth of algae.

How to Minimise Losses of Nitrate Nitrogen?

Nitrification inhibitors: To minimise losses of nitrate nitrogen through volatilisation and leaching, it is desirable to keep nitrogen in the ammonium form. Chemicals that can inhibit the nitrification process are called nitrification inhibitors. Two major compounds that can inhibit nitrification are 2-chloro-6-(trichloromethyl) pyridine commonly known as N-serve and 2-amino-4-chloro-6-methyl pyridine commonly known as AM.

Sulphur coated urea: Urea granules are coated with elemental sulphur. The sulphur slows down the release of urea to the soil solution. It limits hydrolysis of urea to ammonia and the oxidation of ammonia to nitrate. This reduces the availability of nitrate for the denitrification process.

Influence of High Concentration of Added Fertilisers

The added fertilisers salts will almost invariably be localized in higher

The conversion of ammonia into nitrate takes place under following reaction:



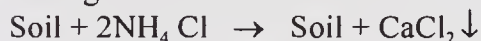
→



→

The H^+ ions released under nitrification process cause acidity in the soil which may be corrected by adding 110kg of lime/100 kg ammonium sulphate.

Ammonium chloride: When applied to the soil, it produces acidity and the soil requires 128 kg calcium carbonate to neutralize the resulting acidic effect of 100 kg of ammonium chloride.



Ammonium fertilisers can be oxidised to nitrates, fixed by the soil solids, or they can be utilised without change by higher plants or micro-organisms.

Nitrate fertilizers: Nitrate fertilisers contain nitrogen in NO_3^- form, which is readily taken up by plants. However, under waterlogged condition, it may be lost due to denitrification. These fertilisers cause alkalinity in soils. Eg. sodium nitrate and calcium nitrate.

Sodium nitrate: It is soluble in water. When added to the soil, the plant roots readily absorb the nitrate ion. NO_3^- being soluble in water is subjected to leaching due to heavy rains. The sodium neutralizes acidity of the soil to a large extent, i.e. 100 kg of NaNO_3 is equivalent to 129kg of CaCO_3 . It leaves basic cations and creates alkaline condition.

Calcium nitrate: The nitrogen present in it is readily soluble in water and easily available to plants. It improves the physical properties of soil. Nitrate salts can be lost by volatilisation or leaching or they can be absorbed by plants or micro-organisms. In most soil situations, the effects of higher localised concentrations of fertiliser materials on nitrogen transformation are not serious.

Mixed ammonical cum nitrate fertilizers: This group contains fertilizers which have ammonical as well as nitrate form of nitrogen.

Calcium ammonium nitrate: It contains 25–26% nitrogen, half of which is in NH_4^+ form and rest half in NO_3^- form. Except this it contains about 35.5% calcium carbonate and 5.5% magnesium carbonate, which are mixed with fertilisers. Heavy irrigation after its application should be avoided as it contains 50% nitrogen in the form of NO_3^- which may be lost due to leaching. This can be mixed with other phosphatic and potassium fertilisers if the mixture has to be applied within few days of mixing.

Ammonium sulphate nitrate: It is a double salt of ammonium nitrate and ammonium sulphate made by neutralising a mixture of nitric and sulphuric acids with ammonia. It contains 26% nitrogen. The nitrogen present in it constitutes about 76% ammoniacal and rest 24% nitrate form. It reacts quicker than ammonium sulphate due to presence of nitrate form of nitrogen, which is readily available to plants. There is negligible loss of nitrogen from this fertiliser. It is non-hygroscopic in nature due to which it does not cake easily but, if stored in moist conditions, caking may take place. Being totally water soluble it does not leave residual nitrogen except that of acidity which may be neutralised by adding 85 kg of CaCO_3 /100 kg of ammonium sulphate nitrate.

Effect of ammonium sulphate nitrate on soil: It is acidic fertiliser and causes acidity due to which it is not suitable for acidic soils. It helps in neutralising alkalinity and is best fertiliser for marginally saline soils having a pH up to 8.5.

Effect of ammonium sulphate nitrate on crop plants: The nitrogen is slowly mineralised or made available to plants and both recovery and fertiliser use efficiency is found to be relatively much better. It also contains 12% sulphur, a secondary nutrient element, which improves plant growth, yield and quality.

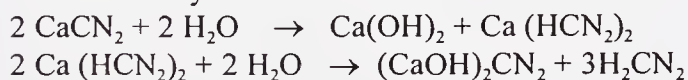
Ammonium nitrate: It is one of the quick acting nitrogenous fertilisers and a representative fertiliser sample contains 35% of nitrogen, half of which is in ammoniacal form and rest half in nitrate form. Of the total nitrogen only 95% is available to plants, *i.e.* nitrogen in nitrate form is fully available but that in ammoniacal form is only 90% available to plants. The fertiliser is fully soluble in water hence it leaves no residue in the soil.

Effect of ammonium nitrate on soil: Being acidic in nature it causes acidity when applied to the soil which may be corrected by liming through addition of CaCO_3 at the rate of 60 kg/100 kg of fertiliser. The ammonium nitrate should not be used under waterlogged conditions because the nitrate nitrogen gets lost through leaching or washing. Heavy soil types are best suited for its application because such soils may retain nutrient for longer time.

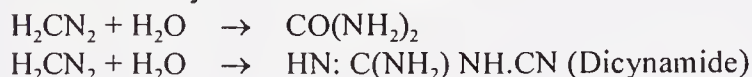
Anhydrous ammonia: It is a cheapest source of nitrogen, as it does not need processing. It is injected in the soil at a high pressure nearly 7.5 to 10 cm below the surface. Immediately after application the soil must be sealed through compaction to avoid losses due to volatilisation. It is found that losses are much less in coarse textured soils than in fine textured soils. Slightly higher moisture reduces the loss of ammonia hence the field should be worked slightly below the field capacity.

Use of calcium cyanamide as a fertilizer: It supplies free lime in soils and adds calcium to the soil. Calcium gets released and the cyanamide reacts with soil colloids where it produces urea and dicyanamide depending upon soil reaction *i.e.* in acidic or in neutral conditions, urea is formed. This process is found to be more rapid in fine grained and moist soils than in coarse and dry soils. In alkaline reactions calcium cyanamide produces dicyanamide.

Reaction of Cyanamide in Neutral and Acidic Soils



Reaction of Cyanamide in Alkaline Soils



PHOSPHORUS CYCLE

- The phosphorus cycle in and above the soil surface is shown in Fig. 18.4. Phosphorus undergoes unique transformation reactions in different soils. Unlike nitrogen, there are no gaseous losses of P and leaching loss with percolating water is negligible.

- Crop residues, animal manure and chemical fertilisers are the primary sources of phosphorus. Transformation of P in soil involves both inorganic and organic reactions.
- The decrease in the soil solution P concentration with adsorption by plant roots is buffered by both inorganic and organic P fractions in soils.
- Numerous soil micro-organisms digest plant residues containing P and produce many organic P compounds in soil. These organic P compounds can be mineralized through microbial activity to supply soluble P. Inorganic P adsorbed on mineral and clay surfaces as H_2PO_4^- or HPO_4^{2-} also can de-sorb to buffer decreases in solution P.
- Primary and secondary P minerals dissolve to resupply $\text{H}_2\text{PO}_4^-/\text{HPO}_4^{2-}$ in solution. Water-soluble fertilizer P applied to soil readily dissolves and increases the concentration of soil solution P. Again, the inorganic and organic P fractions can buffer the increase in solution P.
- From the cycle it is clear that the adsorbed P and the other solid forms are all in equilibrium with the solution P and thereby with each other.

PHOSPHORUS COMPOUNDS IN SOILS

Organic and inorganic forms of phosphorus occur in soils and both the forms are important to plants as sources of phosphorus. The relative amounts of phosphorus in organic and inorganic forms vary greatly from soil to soil.

Organic Phosphorus Compounds

Organic phosphorus represents about 50% of the total P in soils (varies

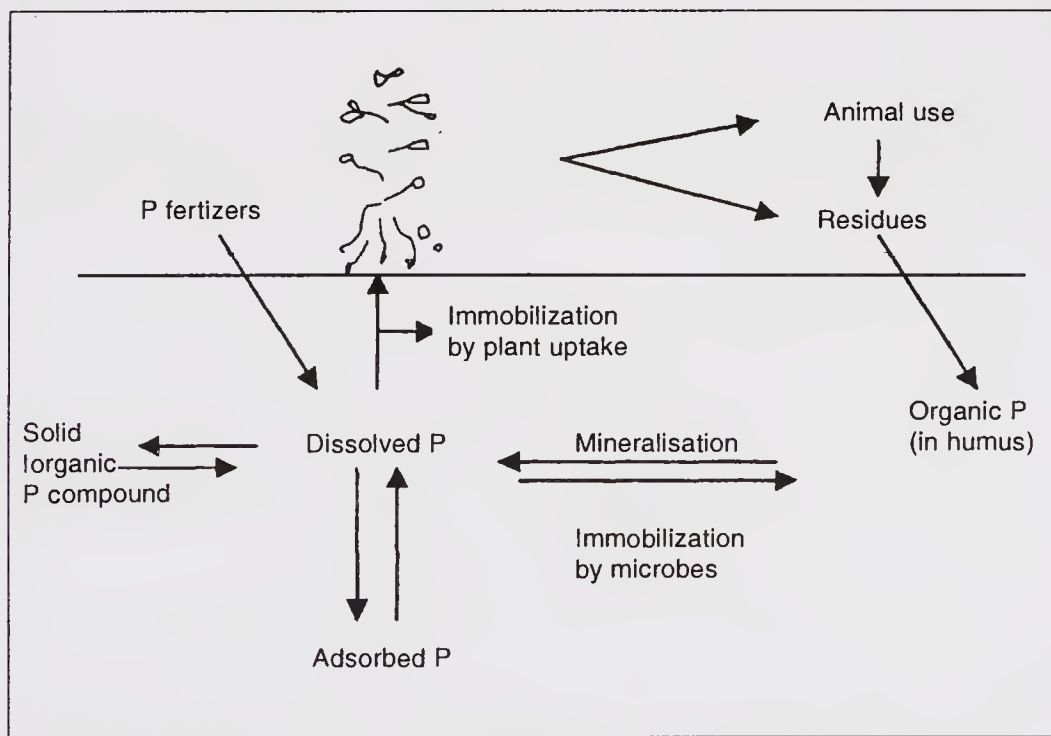


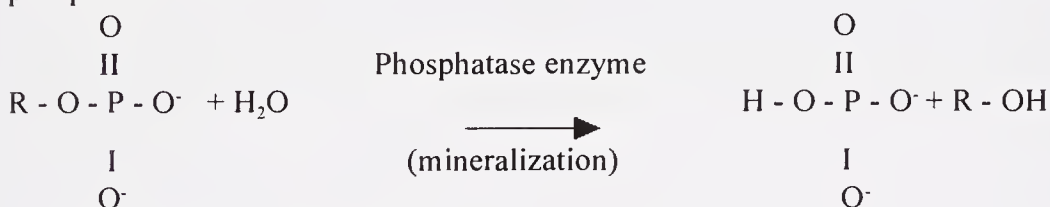
Fig. 18.4. Phosphorus Cycle

between 15 and 80% in most soils). Most organic P compounds are esters of orthophosphoric acid and have been identified primarily as (a) inositol phosphates, (b) phospholipids and (c) nucleic acids.

Inositol phosphates: Inositol phosphates represent a series of phosphate esters ranging from monophosphates up to hexaphosphates. Phytic acid, which has an empirical formula $(CH)_6 (H_2PO_4)_6$, has six orthophosphate (H_2PO_4) groups attached to each C atom in the benzene ring. Phytin, (a Ca-Mg salt of phytic acid), is the most abundant of the known organophosphorus compounds in soils. The total proportion of inositol phosphates in soil is 10–50%.

Phospholipids: Phospholipids, phosphorus containing fatty compounds, are insoluble in water but are readily utilized and synthesized by soil micro organisms. Some of the most common phospholipids are derivatives of glycerol. The rate of release of phospholipids from organic sources in soils is rapid. Phospholipids constitute 1-5% of total organic P in soil.

Nucleic acids: Nucleic acids occur in all living cells and are produced during the decomposition of residues by soil micro-organisms. Two distinct forms of nucleic acids, ribonucleic acid (RNA) and deoxyribonucleic acid (DNA), are released into soil in greater quantities than inositol phosphates, and they are broken down more quickly. Nucleic acids constitute 0.2 to 2.5% of total organic P in soil. Enzyme phosphatase (enzymes responsible for splitting of phosphates from complex organic molecules) plays a major role in the mineralization of organic phosphates in soil.



Inorganic Phosphorus Compounds

Most inorganic phosphorus compounds in soil fall into one of the two groups: (a) those in which calcium is the dominant controlling cation (calcium phosphates) and (b) those in which iron and aluminum are the controlling cations (iron and aluminium phosphates)

Calcium phosphate: The original natural source of phosphorus is the mineral apatite, a calcium phosphate that is nearly insoluble. Apatite minerals may be found in even the more weathered soils, especially in their lower horizons. This fact is an indication of the extreme insolubility and consequent unavailability of the phosphorus contained therein. The simpler compounds of calcium such as mono and dicalcium phosphates are readily available for plant growth. These compounds are present in extremely small quantities only because they easily revert to the more insoluble forms.

Iron and aluminum phosphates: The compounds involved are probably hydroxy phosphates such as (a) strengite — iron phosphate and (b) variscite — aluminum phosphate.

Strengite and variscite are too insoluble to contribute much to plant nutrition. Smeck (1973) suggested that the accumulation of iron and aluminum phosphates is a good indication of the stage of soil development.

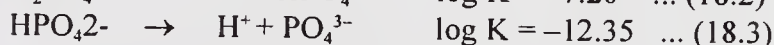
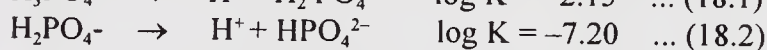
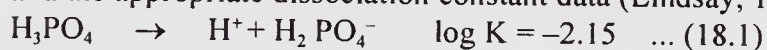
Table 18.5. Common P minerals found in acid, neutral and calcareous soils
(Minerals are listed in order of decreasing solubility)

Acid soils	
Strengite	Fe PO ₄ · 2H ₂ O
Variscite	AlPO ₄ · 2H ₂ O
Neutral and calcareous soils	
Dicalcium phosphate dihydrate (DCPD)	CaHPO ₄ · 2H ₂ O
Dicalcium phosphate (OCP)	CaHPO ₄
Octacalcium phosphate (OCP)	Ca ₈ H(PO ₄) ₃ · 2-5H ₂ O
B-tricalcium phosphate (b-TCP)	Ca ₃ (PO ₄) ₂
Hydroxyapatite (HA)	Ca ₅ (PO ₄) ₃ OH
Fluorapatite (FA)	Ca ₅ (PO ₄) ₃ F

The most common P minerals found in acid soils are Al-P and Fe-P minerals, while Ca-P minerals predominate in neutral and calcareous soils (Table 18.5)

pH AND PHOSPHATE IONS

Plants adsorb phosphorus largely as orthophosphate ions (H₂PO₄⁻ / HPO₄²⁻), that are present in the soil solution. The amount of each form present depends on soil solution pH. It is, therefore, worth to consider how the dissociation of phosphoric acid, H₃PO₄, changes with solution pH. The dissociation reactions, and the appropriate dissociation constant data (Lindsay, 1979), are as follows:



It is possible to express each of the species present in terms of H₂PO₄⁻. Rewriting equation (18.1) in the standard mass action form gives:

$$\frac{[\text{H}^+][\text{H}_2\text{PO}_4^-]}{[\text{H}_3\text{PO}_4]} = 10^{-2.15}$$

$$\text{Or, } [\text{H}_3\text{PO}_4] = \frac{[\text{H}^+][\text{H}_2\text{PO}_4^-]}{10^{-2.15}} \quad \dots (18.4)$$

Similarly, from (18.2),

$$\frac{[\text{H}^+][\text{H}_2\text{PO}_4^{2-}]}{[\text{H}_2\text{PO}_4^-]} = 10^{-7.20} \quad \dots (18.5)$$

And from (18.3), we get,

$$\text{Or, } [\text{PO}_4^{3-}] = \frac{10^{-12.35} [\text{HPO}_4^{2-}]}{[\text{H}^+]} \quad \dots (18.6)$$

Combining (18.5) and (18.6) gives:

$$[\text{PO}_4^{3-}] = \frac{(10^{-7.20}) (10^{-12.35}) [\text{H}_2\text{PO}_4^-]}{[\text{H}^+]} \quad \dots (18.7)$$

The mole fraction of H_2PO_4^- , MF, is given by its concentration of all the phosphate species present, each of which may be expressed in terms of H_2PO_4^- . Thus:

$$\text{MF} = \frac{1}{10^{2.15} [\text{H}^+] + 1 + 10^{-7.20} / [\text{H}^+] + 10^{-19.55} / [\text{H}^+]^2} \quad \dots (18.8)$$

From which it is possible to calculate the mole fraction of H_2PO_4^- at any specified pH. The same approach may be employed to calculate the mole fractions of other species present. The results are most conveniently expressed in graphical form (Fig. 18.5)

At pH 7.2 there are approximately equal amounts of H_2PO_4^- and HPO_4^{2-} . Below this pH, H_2PO_4^- is the major form in soil solution, whereas HPO_4^{2-} is the predominant form above pH 7.2.

PHOSPHORUS FIXING POWER OF SOILS

Crop uptake of fertilizer phosphorus rarely exceeds 20 to 25% in a single cropping season. This is due to the various physico-chemical and biological transformations that revert the soluble P into insoluble forms. The soil factors that affect transformations are pH, organic matter, temperature, mineralogical composition, free sesquioxide content, microbial population and root exudates.

It is difficult to make a comparison of the values of phosphate-fixation capacity given by various workers in different soils and clays, as the amount fixed varied with the method used. Although soils fix phosphate to varying degrees, the amount so fixed is not entirely lost. It builds up the reserves of soil P and adds to the soil

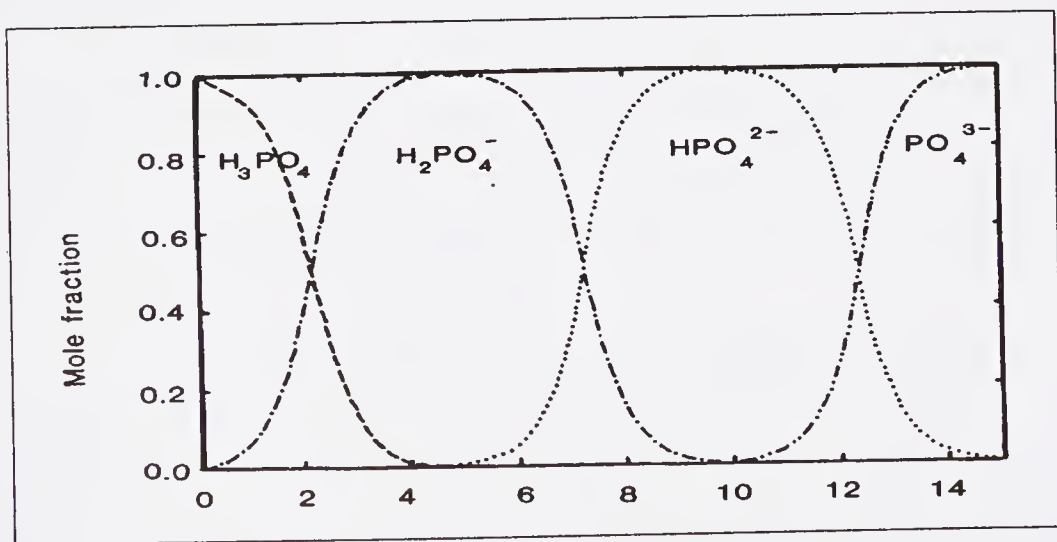


Fig. 18.5. Anionic forms of phosphorus in soil solution as a function of soil pH

P available to plants. Since phosphate is a relatively immobile nutrient, the fixation of phosphate improves the P status of the soils. Under suitable systems of soil management, this fixed phosphorus can be made available to the crop. The residual value of applied fertilizer phosphate in subsequent years is largely due to this phenomenon of phosphate fixation.

Amongst the various soil groups, black, red, laterite, mixed red and black, red and yellow and coastal alluvial soils exhibited higher P fixation than alluvial, gray brown, desert and other soils. Gupta (1965) observed the relationship of phosphate fixing capacity to added phosphate (Table 18.6) which reveals that the maximum phosphate-fixing capacity is in the order: red soil > medium black > heavy black > alluvium grey brown > alluvial soils. Khanna and Mahajan (1971) studied the behaviour of added phosphates in soils of varying physical properties. They observed that more than half of the conversion of added phosphates was in the form of aluminium phosphate: 47-73% at pH 4.7 and 35-56% at pH 6.6; followed by Fe-phosphate, 18-44% at pH 4.7 and 17-34% at pH 6.6. In alkaline and calcareous soil, saloid bound P and Ca-P were much more than in acid soil.

Phosphate Retention and Fixation

Phosphate anions can be attracted to soil constituents with such a bond that they become insoluble and not easily available to plants. This process is called phosphate fixation or retention. Many authors use the term fixation and retention interchangeably. However, Tisdale and Nelson (1975) are of the opinion that retention refers to that part of adsorbed phosphorus that can be extracted with dilute acids. This fraction is relatively available to plants. The term fixed on the other hand is reserved for the portion of soil phosphorus that is not extractable by dilute acids. This portion of phosphorus is not readily available to plants.

Soil pH, organic carbon, exchangeable $\text{Ca}^{2+} + \text{Mg}^{2+}$ and K^+ were highly related to I_0 . DPBC did not relate significantly to soil properties and available P. I_0 and available P were highly related to each other ($r = -0.966$) indicating the good equilibrium between I_0 and Q (Table 18.7).

Table 18.6. Relationship of the P-fixation capacity to phosphate added in some Indian soil

Location	Type of soils	P fixed / added
Delhi (UT)	Alluvial soil	0.26
Bikramganj (Bihar)	Old alluvium	0.36
Katihar (Bihar)	New alluvium	0.38
Kanke (Bihar)	Red loam	0.36
Aduthurai (Tamil Nadu)	Alluvial soil	0.56
Compatore (Tamil Nadu)	Black soil	0.48
Ludhiana (Punjab)	Grey brown	0.71
Pune (Maharashtra)	Medium black	0.75
Ranaghat (W. Bengal)	Alluvium	0.80
Powerkheda (Madhya Pradesh)	Heavy black	0.81
Hyderabad (Andhra Pradesh)	Medium black	0.81
Naihati (W. Bengal)	Red soil	0.85

Source: Gupta (1965)

Table 18.7. Correlation coefficients between soil properties and quantity –intensity parameters of P.

Soil property	'r' values		
	I ₀	DPBC	Avail. P
pH	–0.970**	0.264	0.935**
Organic Carbon	–0.800	–0.318	0.958**
Exch. Ca ²⁺ + Mg ²⁺	–0.981**	–0.430	0.965**
Exch. K ⁺	–0.928	–0.389	0.965**
Avail. P	–0.966**	–0.383	
DPBC	0.380		

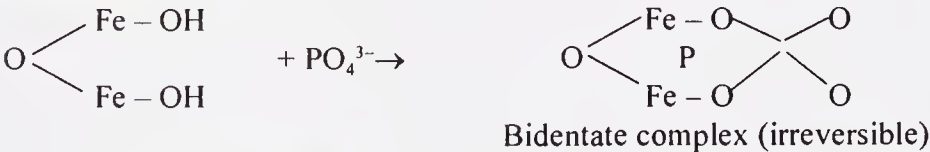
** Significant at 1% level
I₀ – equilibrium phosphate potential DPBC–Differential phosphate buffering capacity
Source: Patiram (1994)

The addition of manure raised the soil pH, organic carbon, available P, CEC, exchangeable Ca²⁺ + Mg²⁺ and K⁺ and decreased the amount of exchangeable Al³⁺ (Patiram & Singh 1993). It may be the combined effect of release from manure and the effect of organic acids on soil minerals, which has the positive effect on the quantity and intensity parameters of P supplying capacity of soil.

Phosphate Retention

- Acid soils usually contain significant amounts of soluble and exchangeable Al³⁺, Fe³⁺ and Mn²⁺ ions. Phosphate, when present, may be adsorbed to the colloid surface with these ions serving as a bridge. This phenomenon is called co-adsorption. The phosphate retained in this way is still available to plants. Such a reaction can also take place with Ca -saturated clays.
- Ca clay adsorbs large amounts of phosphate. The Ca²⁺ ions form the linkage between the clay and phosphate ions as: Clay - Ca - H₂PO₄
- The phosphate ions can also enter into a chemical reaction with the foregoing free metal ions as: Al³⁺ + 3H₂PO₄[–] → Al (H₂PO₄)₃ ↓ The product formed is not soluble in water and precipitates from solution. With the passage of time the Al phosphate precipitates, become less soluble and less available to plants. The lower the soil pH, the greater the concentration of soluble Fe, Al, and Mn; consequently, larger the amount of phosphorus retained in this way.

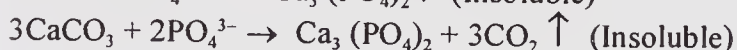
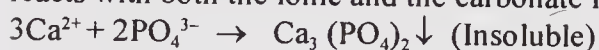
Phosphate fixation in acidic soils: Many acidic soils contain high amounts of free Fe and Al and of Fe and Al hydrous oxide clays. The free Fe, Al and the sesquioxide clays react rapidly with phosphate, forming a series of not easily soluble hydroxy phosphates.



The amount of phosphorus fixed by this reaction usually exceeds that fixed

by phosphate retention. Generally, clays with low sesquioxide ratios ($\text{SiO}_2/\text{R}_2\text{O}_3$) have a higher P-fixing capacity.

Phosphate fixation in alkaline soils: Many alkaline soils contain high amounts of soluble and exchangeable Ca^{2+} and, frequently, CaCO_3 . Phosphate reacts with both the ionic and the carbonate form of Ca.



Phosphate fixation cannot be avoided entirely, but it may be reduced by addition of competing ions for fixing sites. Organic anions from stable manure and silicates are reported to be very useful in reducing P fixation.

The following salient conclusions can be drawn from the results of phosphate fixation obtained.

- The role of clay minerals such as muscovite and phlogopite in P fixation is important. There exist a good correlation between the clay content and P fixation. Thus clay fraction in soils seems to be the site of phosphate fixation.
- Free CaCO_3 present in calcareous soil adsorbs phosphate.
- Organic matter in soils influences P fixation both directly and indirectly. Directly, phosphate can be adsorbed by organic matter, the clay complex and the chelating compounds; indirectly, the organic acids released during the decomposition of organic matter affect phosphate solubilization and fixation.
- Oxides of iron and aluminium combine with phosphates to form metal phosphate. This causes reversion of soluble P into insoluble products.
- In calcareous and alkaline soils, too, the amount of free sesquioxides is highly correlated with phosphate fixation.
- A significant amount of phosphorus is leached out in saline and alkali soils. This is due to formation of highly soluble sodium phosphates. The presence of monocalcium phosphate in soil and sodium carbonate in presence of water leads to formation of soluble sodium phosphates.

THE POTASSIUM CYCLE

The major components of the potassium cycle are shown in Fig 18.6.

- Primary soil minerals such as micas and feldspars are the native sources of potassium. They weather to fine micas (illite) and other silicate clays in which some of the potassium is held in a non-exchangeable, but slowly available form. Kaolinite, halloysite, nacrite and diorite are important 1:1 clay minerals containing potassium.
- The non-exchangeable potassium is slowly released to the exchangeable form and later to the soil solution, from which it is adsorbed by plant roots, and is eventually recycled through plant residues and wastes to the soil.

FORMS AND AVAILABILITY OF POTASSIUM IN SOILS

Potassium in soil occurs in four phases namely soil solution phase, exchangeable phase, non-exchangeable phase and mineral phase. The different

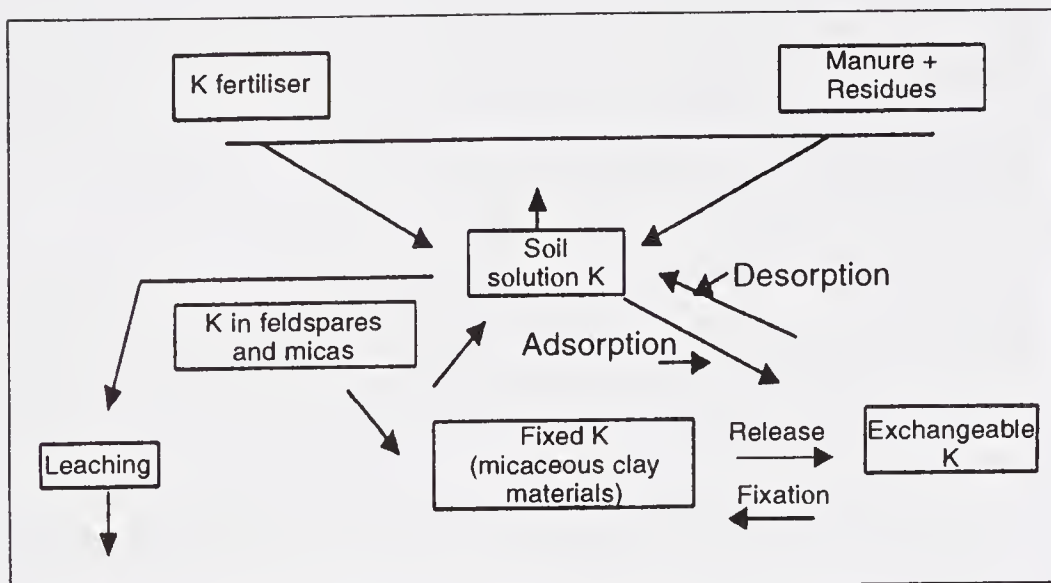


Fig. 18.6. The potassium cycle

forms are in dynamic equilibrium with one another. All the forms of soil potassium were interrelated, indicating the existence of dynamic equilibrium among them (Table 18.8).

Distribution of total potassium in soil as well as in the different size fractions of the soil is controlled to a large extent by clay fraction of soil. The forms of potassium in soils were positively and significantly correlated with K content in silt and clay. (Venkatesh and Satyanarayan, 1994).

Water soluble K: The water soluble K is the fraction of soil potassium that can be readily adsorbed by the growing plants. However this is a very small fraction of total K. The dilution of the soil increases the concentration of water-soluble K and drying decreases it further. It is about 1 to 10 mg kg⁻¹ of total K.

Exchangeable K: Exchangeable K is held around negatively charged soil colloids by electrostatic attraction. Thus, exchangeable potassium represents that fraction of K, which is adsorbed on external and accessible internal surfaces. It is about 40 to 60 mg kg⁻¹ of total K.

Non-exchangeable (fixed) K: Potassium held at inter lattice positions is

Table 18.8. Correlation amongst different forms of soil potassium

	Water soluble K	Exchangeable K	Non- exchangeable K	Lattice K	Total K
Water soluble K	-	0.71**	0.64**	0.34**	0.38**
Exchangeable K	-	-	0.37**	0.48**	0.50**
Non-exchange. K	-	-	-	0.54**	0.58**
Lattice K	-	-	-	-	0.95**
Total K	-	-	-	-	-

** Significant at one per cent

Source: Venkatesh and Satyanarayan (1994)

generally non-exchangeable. Non-exchangeable K is distinct from mineral K in that it is not bonded covalently within the crystal structures of soils mineral particles. Instead, it is held between adjacent tetrahedral layers of dioctahedral and trioctahedral micas, vermiculites and intergrade clay minerals. It is about 50 to 750 mg kg⁻¹ of total K.

Mineral (lattice) K: Lattice K is a part of the mineral structure and is available to the plants very slowly. (As compared to the non-exchangeable K) Both the rate and amount of lattice K released to plants depend on the quantity of clay, especially the smaller clay particles, and its mineralogy. It is about 5,000 to 25,000 mg kg⁻¹.

For convenience, the various forms of potassium in soils can be classified on the basis of availability in three general groups: (a) unavailable (b) readily available and (c) slowly available.

A dynamic equilibrium of various forms of K in the soil may be shown as:
$$K \text{ (lattice)} \leftrightarrow K \text{ (exchangeable)} \leftrightarrow K \text{ (solution)}$$

When fertilizer K is applied to the soil the reaction goes from right to left.

Considerable amount of K may remain on the exchange complex and the amount fixed on the clay lattice will depend on the type of minerals and their K fixing capacity. Since only a small amount of K remains in the soil solution, a small amount of K (soluble form) can be lost to leaching. Potassium may be carried with soil erosion. It is the major cause of K loss.

Relatively Unavailable Forms

The greatest part (90–98%) of all soil potassium in a mineral soil is in relatively unavailable forms. The compounds containing most of this form of potassium are the feldspars and micas. These minerals are quite resistant to weathering and probably supply relatively insignificant quantities of potassium during a given growing season.

Readily Available Forms

The readily available potassium constitutes only about 1–2% of the total amount of this element in an average mineral soil. It exists in soils in two forms; (i) potassium in soil solution and (ii) exchangeable potassium adsorbed on soil colloidal surfaces. Most of this available potassium is in the exchangeable form (approximately 90%). Soil solution potassium is most readily adsorbed by higher plant and is, of course, subject to considerable leaching loss.

Slowly Available Forms

In the presence of vermiculite, smectite, and other 2:1- type minerals the potassium of such fertilisers as muriate of potash not only becomes adsorbed but may become definitely 'fixed' by the soil colloids. The potassium as well as ammonium ions fit in between layers in the crystals of these normally expanding clays and become an integral part of the crystal. Potassium in this form cannot be replaced by ordinary exchange methods and consequently is referred to as non-exchangeable potassium. As such this element is not readily available to higher plants. This form is in equilibrium, however, with the available forms and consequently acts as an extremely important reservoir of slowly available potassium.

QUANTITY AND INTENSITY FACTORS AS RELATED TO THE AVAILABILITY OF PHOSPHORUS AND POTASSIUM

It is important to be aware of the different forms in which phosphorus / potassium is found in soils. But it is even more important to know a soils ability to maintain sufficiently high levels of phosphorus / potassium in the soil solution to assure satisfactory plant growth. In the Q / I approach, nutrient assessment is measured by three parameters namely quantity, intensity and buffer capacity.

Quantity is the amount of ion, which is present at a definite potential or held at a definite strength in the soil at a particular time. Intensity of an ion is a measure of the length with which it is attached to the electrochemical system. The concentration of the nutrient in the soil solution is a measure of the intensity factor. Buffer capacity is a rate of change of quantity with intensity (dQ / dI) and is a measure of the capacity of the soil to maintain the intensity against depletion. The Q/ I parameters of soil phosphorus and potassium are discussed in the following paragraphs:

Q / I relationship of soil phosphorus: Ramamoorthy and Subramaniam (1960) and Beckett and White (1964) approached the determination of 'capacity' of the soil phosphate by determining the equilibrium concentration of P in soil. They calculated the difference, ΔP , between the initial P concentration of 0.01 M CaCl_2 solutions with added P and the P concentration after shaking with the soil. The relationship of ΔP , which can be positive or negative, after shaking with the soil, was referred to as Q / I plot. They obtained the value of the equilibrium phosphate potential (EPP) by interpolation at $\Delta P = 0$. The slope $\Delta Q / \Delta I$ of the Q / I plot for any given time of shaking is a measure of the phosphate buffering capacity of the soil phosphate to maintain the potential of phosphate in the solution.

Soils vary greatly in their capacity to maintain concentrations or activities at equilibrium levels. This is because the capacity of the soil depends on specific soil properties like the clay content, surface area or surface exchangeable CaCO_3 , the organic matter content and the amount of P that have accumulated as a result of past fertilization.

Q / I relationship of soil potassium: Q / I parameters of potassium can be expressed in a number of ways:

Chemical Potential of K (ΔG)

It is defined as the free energy change associated with replacing one equivalent of K by one equivalent of Ca + Mg, treated as one ionic species.

$$\Delta G = RT \ln \frac{a_k}{\sqrt{a_{\text{Ca} + \text{Mg}}}} \quad \text{where,}$$

R = gas constant (Cal / m⁰K) = 1.99

T = Absolute temperature

a_k = Activity of potassium (mole L⁻¹)

$a_{\text{Ca} + \text{Mg}}$ = Activity of Ca + Mg (mole L⁻¹)

Potential Buffering Capacity (PBC^k)

It is a measure of rate of change of quantity with intensity and is represented by the gradient of Q / I curve.

(c) Activity Ratio (AR_0)

It is a measure of intensity of soil potassium i.e. strength with which potassium ion is attached to electrochemical system of soil.

$$AR_0 = \frac{a_k}{\sqrt{a_{Ca+Mg}}} \quad \text{where,}$$

a_k = Activity of potassium (mole/litre)

a_{Ca+Mg} = Activity of Ca + Mg (mole/litre)

The Q / I relationships are measured by shaking together soil and dilute $CaCl_2$ solutions containing various amounts of KCl for short periods at different soil: solution ratios. K and Ca are determined in the solution while activity ratio and gain or loss of K by the soil are calculated (Beckett, 1964). The Q / I relationship on graphical interpolation gives the equilibrium K_{AR} when K is neither gained nor lost by the soil (Ramamoorthy and Paliwal, 1965).

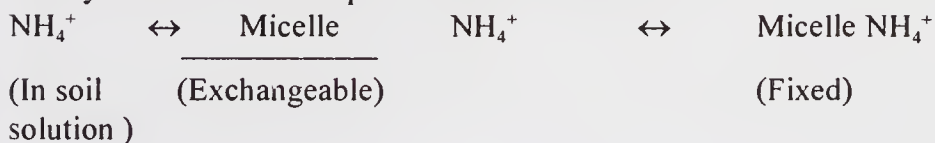
Bele. N, *et al.* 1994 found Q/I relationship of K in surface soil. They found that the activity ratio of potassium (AR^K_0) is higher in the surface than in the subsurface layers. The high values of (AR^K_0) may be attributed to higher ionic strength of K^+ in comparison to Ca^{2+} and Mg^{2+} in soil solution. The PBC^K values increased with depth of the soils and this might be due to accumulation of finer size particles and K reserves. Soils with high content of K and clay showed high PBC^K values. The computed Q/I parameters revealed that the lower and upper parts of the isotherms are linear (Fig. 18.7). Beckett (1964 b) suggested that linear upper part of the isotherm was associated with exchangeable K on planner sites (non-specific sites, K_x) and the lower part with edge and interlattice K (specific sites, K_0) which was held more tightly. Thus, linear lower part indicates small release of K from specific sites. Labile K (K_L), K_x and K_0 values tended to decrease with soil depth. Soils rich in clay content showed higher K_L , K_x and K_0 values than the soils with lower content of clay (Bele *et al.* 1994).

FACTORS AFFECTING AVAILABILITY OF NITROGEN, PHOSPHORUS AND POTASSIUM IN SOIL

The availability of a nutrient, present in the soil or applied as fertilizer, is governed by the net effect of a series of physical, chemical and biological reactions in the soil.

Nitrogen: Fixation by Clay Minerals and Organic Matter

On an average 10% of the total nitrogen is fixed as ammonium ion, vermiculite, fine-grained micas and potassium ions. These ions are fixed into the cavities between the crystal units of these minerals, and are fixed as a rigid part of the crystal. This can be represented as follows:



NH_4^+ ions held in non-exchangeable form are released slowly to higher plants and micro-organisms. Ammonium fixation by clay minerals is generally greater

in sub-soils than in top soil because of the higher clay content of sub-soils. The organic matter also fixes ammonia. It is not of great significance as the fixed ammonia is subject to very slow release by mineralization.

The various transformations of soil and fertilizer nitrogen are affected by

(i) Mineralization (ii) Nitrification (iii) Denitrification (iv) Leaching (v) Urea hydrolysis (vi) Ammonia volatilization (vii) Chemical fixation by soil minerals (viii) Immobilization.

Besides this nitrogen availability is controlled by several other factors as listed below.

- Total N content in soils depends on temperature, rainfall and altitude. It is observed that in black soils total N content increased as the rainfall increased.
- Deforestation and cultivation lower the N content in soils.
- Several workers have observed an increase in total N content of soils under continuous application of farmyard manure, compost and other organic materials.
- Growing of legumes increases N content.
- Ammonium content in soils is negatively correlated with soil pH. Exchangeable ammonium is found to increase with clay content, CEC and water holding capacity of soils.

Major gains and losses of available soil nitrogen may be explained as follows: Nitrogen is added through nitrogen fixation by symbiotic and nonsymbiotic processes, commercial fertilizers, manure and crop residues, soil organic matter and rains. Nitrogen is simultaneously lost through crop removal, leaching, erosion and volatilization.

Management of soil nitrogen consists of two steps:

- The maintenance of adequate nitrogen supplies in the soil.
- The regulation of the soluble forms of nitrogen (to ensure a ready availability to meet crop demands)

Phosphorus: Because of low organic matter content of Indian soils and the wide average ratio of carbon to phosphorus (100:1), not much work has been done on the forms of organic P in the soils. The values of organic P in subtropical countries like India are very variable. The availability of inorganic phosphorus is affected by (a) soil pH, (b) soluble iron, aluminium and manganese, (c) presence of iron, aluminium, and manganese containing mineral, (d) available calcium and calcium minerals, (e) amount and decomposition of organic matter and (f) activities of micro-organisms.

Most crops do not take more than 10–15% of the phosphorus added through fertilizers during the year, the fertiliser is applied (i) Soil has a tendency to fix the added phosphorus, (ii) Phosphorus is an immobile nutrient. Continued use of phosphate fertilisers increases the level of labile forms of phosphorus in the soil. Thus, it is desirable to apply phosphate fertilizers for future years.

Availability of soil phosphorus is controlled by its application through fertilizers, manure and crop residues, soil organic matter and phosphorus bearing soil minerals. Its removal by crops, leaching, erosion and fixation leads to its losses.

The type and extent of reaction of added phosphate in soils is influenced by several factors such as pH, type and amount of clay and redox potential. Nad *et*

al. (1975) found that clay and free iron oxide contents of soils played an important role in determining the P fixing capacity of soils.

Phosphorus is primarily transported to the root surface through the process of diffusion. Quantity, intensity and buffering capacity of soils determine the supply of P to growing roots of plants (Shailaja and Sahrawat, 1994).

Soil test values of available phosphorus as extracted by different methods are given in Table 18.9.

Potassium: In general, potassium is found in comparatively high levels as compared to other nutrients in soil. Following measures can regulate potassium availability:

- Frequent light application rather than one heavy application of fertilizers because of the following reasons: It is quickly subject to leaching from the soil solution.
 - It is subject to rapid fixation.
 - It is subject to luxury consumption by some crops.
- Application of lime reduces leaching losses of potassium and promotes its utilization power in soils.

The annual loss of available potassium by leaching, erosion exceeds losses of nitrogen and phosphorus.

Continuous cropping without fertilization leads to the depletion of organic matter, available N, P, K, Fe, Mn, Zn, and Cu, whereas continuous fertilisation

Table 18.9. Available P extracted by various extractants

Extractant	Soil: solution ration	Shanking time	Soil test values (mg P kg ⁻¹)	References
0.5M NaHCO ₃ , pH8.5	(a) 1:20 (b) 1:10 (c) 1:30 (d) 1:40 (e) 1:50 (f) 1:20	30 min 30 min 30 min 30 min 30 min 4 h	2.0–9.0 1.5–6.8 0.8–8.3 2.4–8.1 1.5–9.0 4.0–18.0	Olsen et al. (1954)
Bray-I (0.025M HCl+0.03M NH ₄ F)	1:7	60 s	0.7–29.8	Bray and Kurtz (1945)
Bray-II (0.1M HCl+0.03M NH ₄ F)	1:7	40 s	95–998	Bray and Kurtz (1945)
CH ₃ COOH (3%)+CH ₃ COONa (10%), pH	4.8	1:5	5 min	5-208 Morgan
Acetic acid (2.5%), pH 2.6	1:40	2 h	114–1080	Williams and Stewart (1941)
Citric acid (1%)	1:100	4 h	95–1010	Dyer (1894)
NaEDTA (0.1%) + 0.03M NH ₄ F	1:40	30 min	14–85	Datta and Kamath (1959)
0.005M H ₂ SO ₄	1:200	16 h	200–1260	Kerr and von Stieglitz (1938)
0.01M Calcium lactate + 0.001	3.7	1:50	2 h	13-350 M HCL, pH Egner (1932)
0.001M H ₂ SO ₄ + (NH ₄) ₂ SO ₄ (3%),	1:200	30 min	68–1130	Truog (1930) pH 3.0

Source: Milap chand and Dhillon (1994)

Table 18.10. Rating chart for the soil test data for a few selected soil parameters

Soil parameters	Low	Medium	High
Organic carbon	< 0.5%	0.5–0.75%	> 0.75 %
Available nitrogen (N)	< 280 kg ha ⁻¹	280–560 kg ha ⁻¹	> 560 kg ha ⁻¹
Available phosphorus (P)	< 10 kg ha ⁻¹	10–25 kg ha ⁻¹	> 25 kg ha ⁻¹
Available potassium (K)	< 110 kg ha ⁻¹	110–280 kg ha ⁻¹	> 280 kg ha ⁻¹

Source: Velayutham and Bhattacharyya (2000)

had beneficial effect on organic matter and available N, P and K of the soil. Farmyard manure treatment increased available N P & K of the soils (Bharadwaj and Omanwar, 1994).

The beneficial effects of farmyard manure can be explained as follows:

- Direct addition of N P K through farmyard manure to the available pool of the soil.
- The decomposition of organic matter is accompanied by the release of CO₂, which when dissolved in water, forms carbonic acid, which is capable of decomposing certain primary minerals.
- In calcareous soils, CO₂ production plays an important role in increasing the phosphate availability.
- The organic material forms a cover on sesquioxide and thus reduces the fixing capacity of the soil (Tandon, 1987).
- The beneficial effect of farmyard manure on the available K is also due to the reduction of potassium fixation and release of K due to the interaction of organic matter with clay. Besides this there is a direct addition of K in the available K pool of the soil (Tandon, 1988).
- farmyard manure enhances uptake of native and applied P, Ca, Mg, enhances microbial activity, improves root development and lessens toxic effects of manganese and aluminium. (Sharma and Gupta, 1994).

SOIL TESTING

Soil health is judged by soil physical, chemical and biological properties. It indicates the productivity level of a soil for a given crop under a set of conditions. The soils are tested with respect to pH, total soluble salts, organic carbon and available nutrients, i.e. phosphorus, potassium. In special cases micronutrients are also determined. The soils are classified into categories as shown in Table 18.10. Since different crops have different level of nutrient requirement it becomes necessary to judge soil productivity in terms of choice of a particular crop.

References and Suggested Readings

- Handbook on Environmental Aspects of Fertilizer Use. Martinus Nighoff. The Hague from Nutrient management for sustained productivity. Vol. 15 *Proceedings of the International Symposium*, Deptt. of Soils, PAU, Ludhiana (1983).
- Becket, P.H.T. and White (1964).
- Beckett, P.H.T. (1964). *Journal of Soil Science* 15 : 9.

- Bele, N., Sonar, K.R. and Patel, Y.M. (1994). *Journal of Indian Society of Soil Science* **42**: 462–3.
- Bhardwaj, V. and Omnawar, P.K. (1994). *Journal of Indian Society of Soil Science* **42** : 387–9.
- Das, S. and Singh, T.A. (1994). *Journal of Indian Society of Soil Science* **42** : 46–50.
- Dhull, S.K., Singh, A. and Dahiya, S.S. (1989). *Haryana Journal of Agronomy* **5** : 45.
- FAO, Rome 1980. Agriculture towards the year 2000. Food and Agriculture Organization, Rome, Italy.
- Gupta, A.P. (1965). *Agriculture Univeristy Journal of Research*. 14 : 191.
- Gupta, S.K. and Chaudhary, H.L. (1994). *Journal of Indian Society of Soil Science* **42** : 203–8.
- Khanna, S.S. and Mahajan, K.K. (1971). *Proc. Int. Symp. Soil Fertility Evalu.* New Delhi.
- Lindsay, W.L. (1979). *Chemical Equilibrium in Soils*. John Wiley and Sons. New York.
- Malik, R.B., Kumar, K. and Bhandari, A.R. (1994). *Journal of Indian Society of Soil Science* **42**:6–10.
- Milap Chand and Dhillon, N.S. (1994). *Journal of Indian Society of Soil Science* **42** : 278–81.
- Nad, B.K., Goswami, N.N. and Leelavathi, C.R. (1975). *Journal of Indian Society of Soil Science* **23**:319.
- Patiram and Singh, K.A. (1993). *Journal of Indian Society of Soil Science* **41** : 430.
- Patiram (1994). *Journal of Indian Society of Soil Science* **42** : 136–9.
- Ramamoorthy, B. and Paliwal, K.V. (1965). *Soil Science* **99** : 236.
- Ramamoorthy, B. and Subramanian, T.R. (1960). Phosphate potential and phosphate activity in soil with special reference to phosphate availability. *Trans. 7th International Soil Congress on Science* **3**:590.
- Review of Soil Research in India, Part-I, (1982). *12 International Congress of Soil Science*, New Delhi, 8–16 February 1982.
- Shailaja, S. and Saharawat, K.L. (1994). *Journal of Indian Society of Soil Science* **42** : 329–30.
- Sharma, P.K. and Raina, A. (1994). *Journal of Indian Society of Soil Science* **42** : 68–72.
- Sharma, P.K. and Gupta, J.P. (1994). *Journal of Indian Society of Soil Science* **42** : 77–80.
- Smeck, N.E. (1973). Phosphorus: An indicator of pedogenetic weathering processes. *Soil Science*. **115** : 199–206.
- Soni, M.L., Singh J.P. and Vinod Kumar (1994). *Journal of Indian Society of Soil Science* **42** : 17–21.
- Tandon, H.L.S. (1987). Phosphorus research and agricultural production in India. FDCO, New Delhi.
- Tandon, H.L.S. (1988). Potassium research and agricultural production in India. FDCO, New Delhi.
- Tisdale, S.L. and Nelson, W.L. (1975). *From Soil Fertility and Fertilizers* pp. 196–199. Prentice Hall of India, New Delhi.
- Velayutham, M. and Bhattacharyya, T. (2000). Soil resource management from natural resource management for agricultural production in India, 103 pp.
- Venktesh, M.S. and Satyanarayan, T. (1994). *Journal of Indian Society of Soil Science* **42**: 229–33.

QUESTIONS

Q. 1. Fill in the blanks

- i) The available nitrate and ammonium form is only _____ % of the total soil nitrogen.

- ii) Two forms of nitrogen available to plants are _____ and _____.
- iii) Mineralization of organic N involve two reactions, amination and _____.
- iv) Enzyme _____ is important in denitrification.
- v) Ammonium nitrogen is not as readily utilized by most plants as _____ nitrogen.
- vi) Surface runoff of phosphates either as such or with soil erosion which is carried with surface water leads to _____.
- vii) Ammonium sulphate nitrate contains _____ % sulphur.
- viii) The conversion of water soluble P to insoluble form depends on the activity of _____, _____ and Ca in soil.
- ix) Inorganic P is adsorbed on mineral and clay surfaces as _____ and _____ ions.
- x) Organic phosphorus represents about _____ of the total P in soils.
- xi) Phospholipids are derivatives of _____.
- xii) Two distinct forms of nucleic acid are _____ and _____.
- xiii) At pH _____, there are approximately equal amounts of H_2PO_4^- and HPO_4^{2-} .
- xiv) Primary soil minerals such as _____ and _____ are the original sources of potassium.
- xv) Potassium held at interlattice positions is generally _____.
- xvi) The readily available potassium constitutes only about _____ % of the total amount in an average mineral soil.
- xvii) In the Q / I approach, nutrient assessment is measured by three parameters namely quantity, _____ and _____.

Answers

(i) 1-2% (ii) nitrate and ammonium (iii) ammonification (iv) reductase (v) nitrate (vi) eutrophication (vii) 12 % (viii) Fe, Al (ix) HPO_4^{2-} and HPO_4^{2-} (x) 50 % (xi) glycerol (xii) Ribonucleic acid and deoxyribonucleic acid (xiii) 7.2 (xiv) micas and feldspars (xv) non-exchangeable (xvi) 1-2% (xvii) intensity and buffer capacity

Q. 2. Choose the correct answer

- i) The greater part of nitrogen occurs in organic / inorganic forms.
- ii) Most soil nitrogen is unavailable / available to plants.
- iii) Nitrogen deficiency is first observed when older / newer leaves of plants turn yellow.
- iv) The primary source of nitrogen is the atmosphere / soil.
- v.) Denitrification losses can be reduced under anaerobic / aerobic conditions.
- vi) Ammonium ions / nitrate ions are subject to fixation by vermiculite, smectites and organic matter.
- vii) The plants do not absorb / absorb amide nitrogen directly through their roots.
- viii) Ammonium sulfate nitrate is non-hygroscopic / hygroscopic.

- ix) Ammonium nitrate is soluble / insoluble in water.
- x) Mono and Di-calcium phosphate are readily available / not readily available for plant growth.
- xi) The greatest part of all soil potassium in a mineral soil is in unavailable / available forms.
- xii) The annual loss of available potassium by leaching and erosion exceeds / is much less than those of N and P.

Answers

(i) organic (ii) unavailable (iii) older (iv) atmosphere (v) anaerobic (vi) ammonium ions (vii) do not absorb (viii) non hygroscopic (ix) soluble (x) readily available (xi) unavailable (xii) exceeds

Q. 3. Define the following

(i) Nitrogen mineralization. (ii) Aminization (iii) Ammonification (iv) Immobilization (v) Mole fraction of H_2PO_4^- (v) Phosphate fixation (vi) Phosphate buffering capacity of the soil (vii) Chemical potential of K (ΔG) (viii) Potential buffering capacity (PBC^k) (ix) Activity ratio (AR_0) of soil potassium.

Q. 4. Differentiate between the following

- i) Fate of ammonium nitrogen and nitrate nitrogen.
- ii) CAN and ASN (ammonium sulfate nitrate)
- iii) Reaction of calcium cyanamide under acidic soils and alkali soils. (iv) phytic acid and phytin

Q. 5. Write short notes on the following

(i) Fixation of nitrogen by clay minerals and organic matter (ii) Nitrification (iii) Nitrification inhibitors (iv) Use of anhydrous ammonia as a source of nitrogen (v) Non-exchangeable potassium (vi) Q / I relationship of soil phosphorus (vii) Management of soil phosphorus (viii) Soil testing.

Q. 6. Comment on the following statements

- i) Nitrogen availability depends upon the rate at which organic nitrogen is converted to inorganic nitrogen.
- ii) Ammonium fixation by clay minerals is generally greater in sub-soils than in topsoil.
- iii) NO_2^- generally does not accumulate in soils
- iv) Nitrification is a two step process
- v) Nitrate nitrogen is easily leached from permeable soil
- vi) De-nitrification losses can be reduced by improved soil drainage
- vii) Nitrate nitrogen has a greater propensity towards leaching as compared to ammonium nitrogen
- viii) Most of the phosphorus present in soils is not readily available to plants
- ix) Nitrogen fertilizers may be grouped into four classes
- x) Urea should be applied in moderately, moist conditions 5 cm deep
- xi) Ammonium sulfate is an excellent fertilizer for wetland rice

- xii) Application of ammoniacal fertilizers causes soil acidity
- xiii) Nitrate fertilizers causes alkalinity in soil
- xiv) Heavy irrigation after application of CAN should be avoided
- xv) Ammonium nitrate should not be used under waterlogged conditions
- xvi) The soil must be sealed through compaction after application of anhydrous ammonia
- xvii) The various P fractions attain an equilibrium with water soluble P in soil solution
- xviii) Phosphorus undergoes unique transformation reactions in different soils
- xix) Apatite minerals may be found in even the more weathered soils
- xx) Mono and di-calcium phosphates are present in extremely small quantities
- xxi) Accumulation of iron and aluminium phosphates is a good indication of the stage of soil development
- xxii) It is possible to calculate the mole fraction of H_2PO_4^- at any specified pH
- xxiii) Added phosphorus builds up the reserves of soil P and adds to the soil, P available to plants
- xxiv) There exists a dynamic equilibrium in various forms of K in soil
- xxv) Non-exchangeable potassium serves as an extremely important reservoir of slowly available potassium
- xxvi) Most crop plants do not take more than 10 - 15 % of the phosphorus added through fertilizers

Q.7. Answer the following in brief

- i) Enlist important functions of nitrogen in plants
- ii) Enlist symptoms of nitrogen toxicity in plants
- iii) Enlist the ways of loss of nitrogen
- iv) Enlist factors affecting leaching losses of nitrate nitrogen
- v) Name any five Genera of bacteria involved in denitrification
- vi) Enumerate the biochemical pathway leading to denitrification losses
- vii) What is the fate of fertilizer N and P after application to crops
- viii) What are the advantages of sulphur coated urea
- ix) How is urea hydrolysed in soil. Give equations
- x) Explain the reactions of ammonium sulphate and ammonium chloride in soil
- xi) What is the chemical composition of calcium ammonium nitrate
- xii) Enlist the primary sources of soil phosphorus
- xiii) Enlist important organic P compounds in soil
- xiv) What is the role of enzyme phosphatase in phosphorus mineralization in soil. Give equation
- xv) What are the different forms of inorganic phosphorus compounds in soils
- xvi) Enlist common P minerals found in soils
- xvii) How is potassium recycled into the soil
- xviii) What are different forms of readily available potassium
- xix) What is meant by management of soil nitrogen
- xx) Enlist factors influencing availability of inorganic soil phosphorus
- xxi) Give Rating-chart for soil test data in terms of organic carbon, available N, P & K.

Q.8. Answer the following in detail

- i) Describe nitrogen cycle
- ii) Classify nitrogenous fertilizers with chief characteristics of two fertilizers of each category
- iii) Describe phosphorus cycle
- iv) Explain the mechanism of phosphate retention with respect to (i) Al^{3+} Fe^{3+} and Mn^{2+} ions (ii) Ca-clay (iii) Free metal ions like Al^{3+}
- v) Explain the mechanism of phosphate fixation in acidic and alkali soils
- vi) What are different methods to express Q / I parameters of soil potassium. Discuss.

Q.9. Give diagrammatic view of the following

- (i) Nitrogen cycle (ii) Equilibrium relations among soil solution P and the various fractions of the element in soil (iii) The phosphorus cycle (iv) Anionic forms of phosphorus in soil solution as a function of soil pH (v) The potassium cycle.



Chemistry and Availability of Secondary Nutrients

SECONDARY nutrients include sulphur, calcium and magnesium. Secondary elements are required in very small quantity as compared to primary elements.

Sulphur: In 1911, Peterson discovered the essentiality of sulphur for plant growth. Sulphur in the form of sulfate is essential for all plants. It is needed in almost similar quantities as phosphorus or magnesium. Involvement of sulphur in plant metabolism and yield responses makes sulphur as the fourth major element after NPK. The depletion of sulphur and other micronutrients has increased in soils due to intensive agriculture involving use of high yielding varieties, scarce use of organic manure and high use of sulphur and micronutrient free high analysis fertilizers.

IMPORTANCE OF SULPHUR

Sulphur in Soils

- Sulphur is the thirteenth abundant element in the earth's crust, average ranging between 0.06 to 0.10%. Sulphur in soils is being derived from weathering of rocks and soils, i.e., gypsum, barite, epsomite, mirabilite.
- The C:N:S ratio of soil organic matter is approximately 125:10:1.2.
- The soils with less than 10 mg/kg available sulphur is considered as low (using mono calcium phosphate as extractant). However, the critical level may range between 8 and 30 mg/kg depending upon the method of extraction, soil type and nature of the crop. Tiwari *et al.* (1983) suggested 10 mg/kg SO_4^{2-} as the critical limit.

Sulphur in Plants

- Sulphur in the form of sulphate (SO_4^{2-}) represents the readily available fraction to the plants. Roots absorb SO_4^{2-} ions by mass flow and diffusion process. SO_4^{2-} ions are transported within the plant in the same form and then reduced to SH (sulfhydryl-group) and incorporated into organic forms.
- Sulphate is mainly translocated in an upward direction and the capability of higher plants to move S in the downward direction is relatively low.
- Sulphur content in the plant ranges between 0.1% and 0.5% with an average of 0.3%. 0.2% S in plants has been considered as a critical limit of deficiency.
- The economic part of the plant (grain, fruits) accumulates higher S content than the non-economic parts. Sulphur uptake is generally 9–15% of the N uptake though it can range from 5–30%.

Table 19.1. Commonly used sources of sulphur

Fertilizer	Sulphur content (%)
Ammonium sulphate $(\text{NH}_4)_2 \text{SO}_4$	24.2
Single super phosphate $\text{CaH}_4(\text{PO}_4)_2 \cdot 2\text{H}_2\text{O}$	13.9
Gypsum $(\text{CaSO}_4 \cdot 2\text{H}_2\text{O})$	18.6
Magnesium sulphate $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	13.0
Pyrites (FeS_2)	13.2
Poultry manure	0.77
Farm yard manure	0.04
Basic slag	3.40
Elemental sulphur	100

Sulphur Containing Fertilizers

- The sulphur requirements of crops are met with fertilizers, atmospheric pollution, irrigation water, farmyard manure, crop residues and sulphur containing pesticides.
- Fertilizer sources of sulphur contribute to a great extent to the need of the crops. There are different sources of sulphur containing fertilizers. Some of the sulphur containing sources including fertilizers is listed in Table 19.1
- Sulphur fertilizers may contain sulphur as the sulphate ion, the other soluble forms or as elemental sulphur. Sulphur in the sulphate form is immediately available to the plant. However, it may be readily leached from the root zone.
- Elemental sulphur takes several months to make it available for the plant. Elemental sulphur has the advantage of providing a long lasting supply of sulphur to the crop.
- Average results of trials conducted under the FAO S-network show that application of 30 kg S /ha increased crop yields by 15–28 %.
- In general, application of 20–50 Kg S /ha to S deficient soils is sufficient to meet the S requirement of crops. When it is known that a field is S deficient, S fertilizer should be used as the basal application. If the crop runs short of S during growth, a readily soluble source such as ammonium sulfate can be used for top dressing to provide N as well.

Factors Affecting Availability of Sulphur

Generally, total S content in the tropical soils of India, is lower than the values reported for the temperate zone soils. Sulphur content in a soil depends largely on its organic matter and organic sulphur content. The low S reserves in the tropical soils have resulted largely from their poor organic matter status. Following factors may affect available S content in a soil:

Soil organic matter: A higher amount of total S has been reported in surface than sub-surface soils. This is due to a higher organic matter content in surface soils. Sulphur is a constituent of organic matter; the amount and nature of organic matter govern its content in soils.

Soil texture: The differences in sulphur content of different textural classes result from the association of organic matter with the clay fraction of the soil.

Table 19.2. Influence of type of vegetation on total and available sulphur in hill soils of Tamil Nadu

Type of vegetation	No. of soils	Organic C (%)	Total S (ppm)	Available S (ppm)
Virgin grassy vegetation	25	3.5	1523	132
Vegetation virgin	54	3.8	1461	139
Cultivated Horticultural Crops	23	3.8	1562	94
Forest vegetation	29	4.0	1408	145
Tea and Coffee	13	3.6	1323	61
Cultivated	46	3.2	1228	66

Source : Palaniappan *et al.* (1978)

Thus finer textured soils contain a higher amount of total and available sulphur than coarse textured soils.

Soil reaction: In general, acidic soil contains a higher amount of sulphur than the alkaline soils. Acidic soils are also high in free Fe and Al oxide, which have higher adsorption capacity for sulphates.

Salt content: Accumulation of S is accompanied by the accumulation of sulfates. High contents of salts in coastal saline and alkaline alluvial soils have resulted from the accumulation of salts of sulfate in these soils. Many workers have reported a positive relation between total S and $\text{SO}_4\text{-S}$.

Climate: Soils located at higher altitude compared with lower altitude contain a higher amount of total and available sulphur. This is largely due to increase in organic matter content of soils because of higher rainfall and lower temperature at high altitude.

Vegetation: Sulphur content declined markedly in cultivated soils (1228 ppm) followed by soil in the tea, coffee (1323) and forest soils (1408 ppm). It increased considerably under horticultural crops (Table 19.2). Grasses are better able to utilize SO_4^{2-} than legumes.

Sulphur Deficiencies

Sulphur deficiency is most common under following conditions: (a) sandy soils: these soils are low in organic matter and subjected to SO_4^{2-} leaching. Crops grown on coarse textured soils are more susceptible to S deficiency, (b) soils with low organic matter content: sulphur being a constituent of organic matter. Crops grown on soils that have < 1.2 to 1.5 organic matter often require S fertilization, (c) soils receiving S-free high analysis fertilizers: these fertilizers do not contain sulphur as impurities, (d) soils that receive little or no organic manure : Since organic manure are good potential natural source of sulphur, (e) soils away from industrial sites: these sites are important source of sulphur supply for its transformation.

Sulphur deficiencies are easy to correct. For example, an application of 40 kg P_2O_5 /ha as SSP will automatically provide 30 kg S / ha (12% S in SSP; 250 kg of SSP will be required. The same amount of S can also be added with a 25 kg N + 40 kg P_2O_5 through ammonium phosphate sulfate (APS) or- 20 - 20 -0 - 15 (N

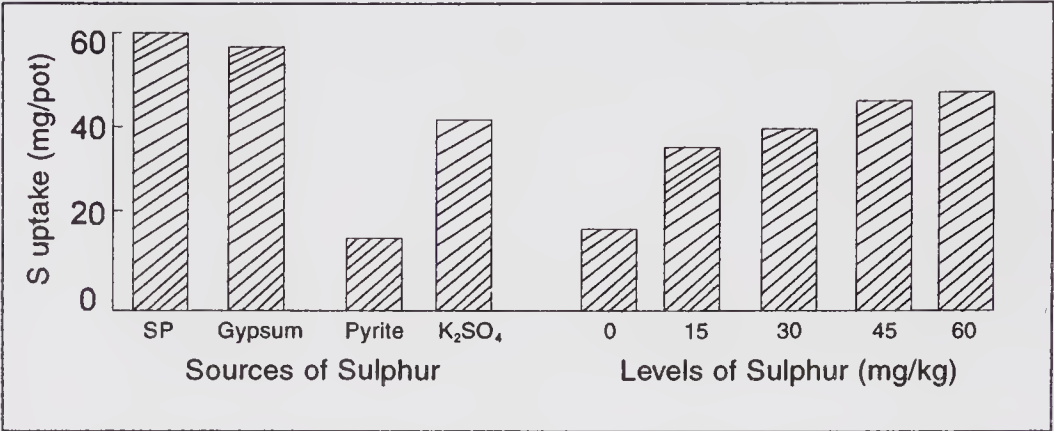


Fig 19.1. Total sulphur removal (grain + straw) by *toria* applied through different sources and levels source: Raj *et al.* (1994)

P K S) or through 170–230 kg gypsum / ha. (33% sulphur fertilizer efficiency is assumed since plants do not remove all S applied in fertilizer). Both N and S are required because they are involved in protein synthesis; the full benefit from the addition of one is dependent on an ample supply of the other.

Sulphur requirements of rice: Rice crop absorbs 2.5–3.5 kg S for every ton of paddy produced. Thus an uptake of 15–21 kg S is associated with a 6 tonnes / ha paddy harvest. During the active tillering stage, rice leaves should contain at least 0.15% S. If the S content falls below this level into the deficiency range, it can lead to a loss in potential yield and also reduce the overall fertilizer use efficiency.

Positive effects of S application on rice yield have been reported from the states of Andhra Pradesh, Delhi, Gujarat, Punjab, Rajasthan, Orissa, Tamil Nadu, Uttar Pradesh and West Bengal. In recent years, informative results have also been obtained from field trials conducted under the FAO sulphur research network.

Raj *et al.* (1994) found that the average values of the total sulphur removal increased with increasing level of S up to 60 mg kg⁻¹ (Fig 19.1) Among different

Table 19.2. Effect of sources and levels of S on oil content (%) of *toria*

Sources	S levels (mg/kg soil)				Mean
	15	30	45	60	
S/P	44.4	43.6	43.4	43.4	43.7
Gypsum	44.2	43.9	44.0	44.6	44.2
Pyrite	44.2	43.5	45.0	45.5	44.5
K ₂ SO ₄	42.8	43.9	42.9	42.4	42.9
Mean	43.8	43.7	43.8	44.0	–
Control	42.3				

CD(P=0.05) S and L = 1.02; S × L = NS

Source: Raj *et al.* (1994), *J. Indian Soc. Soil Sci.* 42(i) : 152–154.

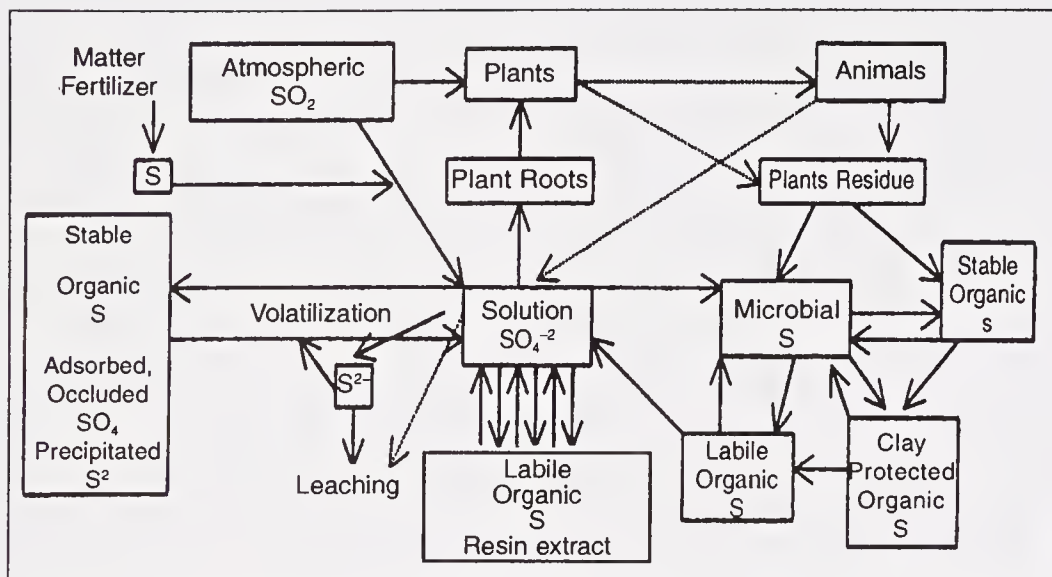


Fig. 19.2. Main forms and transformations of sulphur in the soil plant animal system
Source : Stewart *et al.* (1984).

sources of sulphur, gypsum proved to be better for total sulphur uptake Table 19.3.

Application of sulphur up to 60 kg ha⁻¹ significantly increased the seed weight per head and seed yield of sunflower which might be ascribed to increased protein as well as oil content of the seeds. [Des *et al.* (1994)].

THE SULPHUR CYCLE

Sulphur cycling in the soil - plant atmosphere continuum is shown in Figure 19.2. Some similarity between sulphur and nitrogen cycles is evident.

- The atmosphere is an important source of both the elements i.e. sulphur as well as nitrogen.
- Each is held largely in the organic fraction of the soil and each is dependent to a considerable extent upon microbial action for its various transformation.
- Sulphur goes through a cycle of oxidation in the soil and reduction in the plant much like the nitrogen cycle.
- An exchange between the sulphur of soil and plants and atmospheric sulphur dioxide is an important part of the sulphur cycle.
- Many different microbes can release soluble sulphur by decomposing organic matter.

Sulphur Sources in Soils

The main S-bearing minerals in rocks and soils are

Gypsum (CaSO ₄ ·2H ₂ O),	Epsomite(MgSO ₄ ·7H ₂ O),	Mirabilite(Na ₂ SO ₄ ·10H ₂ O),
Pyrite (FeS ₂),	Sphalerite (ZnS),	Chalcopyrite (CuFeS ₂),
Cobaltite (CoAsS),	Pyrrhotite	(Fe ₁₁ S ₁₂), Galena (PbS),
Arsenopyrite (FeS ₂ ·FeAs ₂),	Pentlandite	(Fe,Ni) ₉ S ₈

- The S content of igneous rock usually ranges from 0.02 to 0.07%. The S content in sedimentary rocks varies from 0.02 to 0.22%.

- Elemental sulphur occurs in deposits over salt domes, in volcanic deposits and in deposits associated with calcite and gypsum.
- Oceans contain approximately 2,700 ppm SO_4^{2-} . In other natural waters SO_4^{2-} ranges from 0.5 to 50 ppm but may reach 60,000 ppm (6 per cent) in highly saline lakes and sediments.
- Another source of soil S is the atmosphere. This is common in regions where coal and other S-containing products are returned (burned back) to earth in precipitation.
- Volatile S compounds are released in large quantities from volcanic activity, from tidal marshes, from decaying organic matter and from other sources.

Sulphur Transformations in Soil

The transformations of sulphur are important indicators of its availability to plants. Availability of sulphur from organic sulphur reserves in soils depends on its mineralization through microbial activity. Sulphur transformations may be affected by following factors:

Soil temperature: An increase in temperature increases the sulphur oxidation rate in the soil. It has been reported that mineralization of element sulphur increased with temperature up to 35° C.

Organic matter: The transformation of element sulphur was faster in soils having low content of organic matter than in those having high organic matter (Chopra 1965). S may be immobilized in soils in which either the C/S or N/S ratio is too large. Immobilization or tie-up of SO_4^{2-} in various organic forms is favoured if the ratio (C/S) is greater than 400.

Soil moisture: Drying of soil enhanced mineralization of organic sulphur, and there was a flush of sulfate sulphur in soils after a prolonged drought (Kanwar 1976). Soil moisture affects the activity of sulphatases, the rate of S mineralization and the movement of SO_4^{2-} in soil. Das (1973) concluded that under both aerobic and submerged incubation a major part of the added sulfate remained in a form available to plants. Under waterlogged conditions formation of hydrogen sulfide may occur. Liming and addition of ammonium sulfate and single superphosphate increased the production of sulfide in these soils. This indicates the possibility of sulfide toxicity in wetland rice crop in certain soils because of sulfate reduction when large amount of sulfate containing fertilizers or amendments are applied.

Soil depth: It is reported that maximum sulphur was in the surface (0-15 cm) soil and decreased with depth (Venkateswarlu 1963). This may be attributed to higher content of organic matter on surface soils.

Type of cations: It has been reported that the oxidation of element sulphur to sulfate was affected by the nature of the cations in the soil in the following order: $\text{Na}^+ > \text{H}^+ > \text{K}^+ > \text{Ca}^{2+} > \text{Mg}^{2+}$. Thus alkali or saline alkali soils in the arid regions have greater amounts of sulfate.

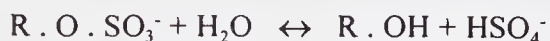
ROLE OF SULPHUR COMPOUNDS IN SOILS AND PLANTS

Forms of sulphur in soils

- Sulphur is present in the soils in both organic and inorganic forms although nearly 90% of the total S in most non-calcareous surface soils exist in organic

forms.

Organic sulphur: Organic sulphur occurs in soil in various forms including carbon-bonded sulfhydryl (-SH) groups and sulfate groups with one of their oxygen bonded to a carbon. The N / S ratio in most soils falls within the narrow range 6 to 8. The important organic fractions in soil are (a) HI- reducible S (reduced by HI), (b) Carbon bonded S (reduced by Ni) and (c) Inert or residual S (does not reduce). As much as 50 % of the total S in surface soils may be present as SO_4^{2-} esters. Enzyme sulfatase hydrolyze esters and release SO_4^{2-} through mineralization as follows:



Inorganic sulphur: The inorganic sulphur forms are:

Solution SO_4^{2-} : Roots adsorb SO_4^{2-} form of sulphur, which reach to the roots by diffusion and mass flow. Levels of readily soluble SO_4^{2-} vary greatly with depth of soil and fluctuate considerably within the profile.

Adsorbed SO_4^{2-} : It is an important fraction in soils containing large amounts of Al and Fe oxides. Many ultisol and oxisol soils contain appreciable amounts of adsorbed SO_4^{2-} . Adsorbed SO_4^{2-} may not be as rapidly available as soluble SO_4^{2-} , but it can be released over longer periods of time.

SO_4^{2-} co precipitated with CaCO_3 : S occurs as a cocrystallized impurity with CaCO_3 and is an important fraction of the total S in calcareous soils. Solubility and availability of this form of sulphur are affected by particle size of CaCO_3 , soil moisture content; common ion effects and ionic strength.

Reduced inorganic sulphur: In waterlogged soils, there may be accumulations of H_2S formed by the decay of organic matter. Sulfide accumulation is limited primarily to coastal regions influenced by seawater. The deep colour of the shore of the 'Black Sea' is caused by the accumulation of FeS_2 .

Role of Sulphur in Plants

Synthesis of Amino Acids

- Sulphur is required for the synthesis of sulphur containing amino acids methionine (21% S), cystine (27% S) and cysteine (26% S), which are essential components of protein.
- It is needed for the synthesis of metabolites including coenzyme A, biotin, thiamin or vitamin B, and glutathione. These coenzymes are responsible for photosynthesis and respiration.
- Sulphur is essential for the chlorophyll synthesis owing to its role in protein synthesis. Chloroplasts are also rich in organic bound sulphur.
- Sulphur containing enzymes are involved in the reduction of nitrate nitrogen to proteins and also in legumes- rhizobium nitrogen fixation.

Component of Substances

- Sulphur is a component of S-adenosylmethionine, ferradoxin, formylmethionine, lipoic acid and sulfolipid.
- Sulphur occurs in volatile compounds (as glucosinolates) responsible for the characteristic taste and smell of plants as in the mustard and onion families. It also enhances oil formation in crops such as flax and soybeans.

- Sulphur is important for the synthesis of lignin and sterols.

Beneficial Effects on Plants

- Glutathione, a sulphur containing compound present in plant cells, plays an important role in detoxification of unfavourable compounds for plant growth.
- Sulphur is the main constituent of diallyldisulphide known for its lachrymatory effect, which imparts characteristic flavour and causes tears in eye, example onion and garlic.
- Sulphur influences the uptake of phosphorus in plant.
- Sulphur in the form of SH group provides cellular resistance to dehydration caused by drought, heat and frost damages and thereby S imparts resistance in plants to these stresses.

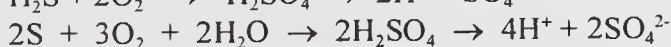
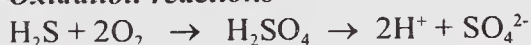
SULPHUR OXIDATION AND REDUCTION

Sulphur oxidation: Sulphur oxidation occurring in soils is mostly biochemical in nature. Sulphur oxidation is accomplished by number of autotrophic bacteria including those of genus *Thiobacillus*, five species of which have been characterized:

- (a) *Thiobacillus thiooxidans* (b) *T. thioparus* (c) *T. nonellus* (d) *T. denitrificans*
(e) *T. ferrooxidans*

In soils, sulfides, elemental sulphur, thiosulphates and polythionates are oxidized.

Oxidation reactions



Thus S-oxidation is an acidifying process.

Sulphur reduction: Sulfates tend to be unstable in anaerobic environments so they are reduced to sulfides by a number of bacteria of two genera, *Desulfovibro* (five species) and *Desulfotomaculum* (three species)

The organisms use the combined oxygen in sulfate to oxidize organic materials.

Reduction reactions



(Organic alcohol) (Sulfate) (Organic acid) (Sulfide)

Also, sulfites (SO_3^{2-}), thiosulfates ($\text{S}_2\text{O}_3^{2-}$) and elemental sulphur (S) are rather easily reduced to the sulfide form by bacteria and other organisms.

The oxidation and reduction of inorganic sulphur compounds are of great importance to growing plants. These reactions determine the quantity of sulfate present in soils at any one time. Also, the state of sulphur oxidation determines to a marked degree the soil acidity as S-oxidation is an acidifying process.

Acid Sulfate Soils

These soils are also called cat clays. The name is derived from Dutch name Katteklei (cat clays). These soils are usually more acidic (pH 4.0). When the soil is drained and aerated, the sulfide is oxidized to sulfate by chemical and bacterial actions, forming sulphuric acid. The oxidation is accentuated in presence of FeS_2 .

Bacteria, *Thiobacillus ferrooxidans* are active oxidizers and builds up acidity. The chemical reactions are as follows:

- Nonbiological

$$2\text{FeS}_2 + 2\text{H}_2\text{O} + 7\text{O}_2 \rightarrow 2\text{FeSO}_4 + 2\text{H}_2\text{SO}_4$$
- Accelerated by bacteria (*Thiobacillus ferrooxidans*)

$$4\text{FeSO}_4 + \text{O}_2 + 2\text{H}_2\text{SO}_4 \rightarrow 2\text{Fe}_2(\text{SO}_4)_3 + 2\text{H}_2\text{O}$$
- Rapid in acid pH (nonbiological)

$$\text{FeS}_2 + 7\text{Fe}_2(\text{SO}_4)_3 + 8\text{H}_2\text{O} \rightarrow 15\text{FeSO}_4 + 8\text{H}_2\text{SO}_4$$

Strong acidity results in toxicities of aluminum and iron, soluble salts, manganese and hydrogen sulfide gas. The reclamation of such soils may be done as follows:

(i) Keep the area flooded. Flooding inhibits acid development, which requires oxidation. (ii) Lime and leach. Acid sulphate soil needs a greater amount of lime.

ROLE OF CALCIUM AND MAGNESIUM COMPOUNDS IN SOIL AND PLANT

Sources of Soil Calcium

The calcium concentration of the earth's crust is about 3.64%. The important sources in soil are: (i) Anorthite $\text{CaAl}_2\text{Si}_2\text{O}_3$ (ii) Calcite CaCO_3 (iii) Dolomite $\text{CaMg}(\text{CO}_3)_2$ (iv) Gypsum $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ (v) Apatites $\text{Ca}_5(\text{PO}_4)_3\text{F}$, $\text{Ca}_5(\text{PO}_4)_3\text{Cl}$, $\text{Ca}_5(\text{OH})(\text{PO}_4)_3$

Calcium in Soils

- Calcium is generally the major base on the exchange complex of soil when the pH is in the range of 5.5 to 6.5. According to Chapman (1975), for example a 'normal' soil would have an exchangeable Ca content of 60 to 85% of the total cation exchange capacity and such soils are nearly neutral in reaction. Soils of humid regions are generally low in Ca. Under these conditions when water containing carbon dioxide percolates through the soil, the carbonic acid displaces Ca (and other bases) from the exchange complex. This results in leaching of Ca and the soils become more acidic. Soils of arid planes of north India where the rainfall is lower as compared with the humid hills; contain higher quantities of calcium carbonate.
- Calcium concentration in the soil when higher than necessary for plant growth will normally have little effect on Ca^{2+} uptake, because Ca^{2+} uptake is largely genetically controlled.
- As a general rule, coarse-textured, humid-region soils formed from rocks low in Ca mineral are low in Ca. This is because of removal of Ca and other cations by excessive leaching through the soil profile.

Sources of Soil Magnesium

Mg constitutes 1.93 % of the earth's crust. Its content ranges from 0.1 % in coarse sandy soils in humid region to 4 % in fine textured arid or semi arid soils. Basalt, periodotite and dolomite are important Mg containing rocks. Under average conditions, exchangeable Mg is about 5% of the soil cation exchange capacity.

Mg in soils is in equilibrium with exchangeable Mg^{++} .

Magnesium in Soil

- Mg-deficiency is common in plants growing on coarse textured acid soils having sandy loam, loamy sand or sand surface.
- Mg deficiency also occurs in soils with high ratios of exchangeable Ca/Mg (This ratio should not exceed 10 to 15). The magnesium deficiency is widespread in the soils of West coast of India, which receives a high rainfall during south-west and north-east monsoon seasons. The mean annual rainfall of this area varies from 3000 to 4000 mm, where the soil forming processes are dominantly controlled by precipitation.
- Acid soils with pH 5.0 and below are liable to exhibit Mg deficiency. Thus Mg deficiency is created when higher dose of ammonium sulfate was added to low exchangeable Mg^{++} soils.
- A high dose of potassium fertilizers on sandy soils induces Mg deficiency. Generally the recommended K/Mg ratios are < 5 for field crops, 3 for vegetables and sugarbeets and 2 for fruit and green house crops.

Calcium in Plants

The plants from the soil remove large quantities of calcium. In the ash of the vegetative parts of a citrus tree, for example, Ca constitutes about 34%, the highest of any other nutrient. Calcium is taken up by the plants in the form of Ca^{++} ion either from the soil solution or from the clay complex. Although Ca is present in plants in relatively higher proportion as compared with many of the other major elements, yet its actual requirement by plants is not much higher than that of a micronutrient (Burstron, 1968). Some higher plants could be grown in a solution containing only a few ppm of Ca, provided other potentially toxic (but essential) ions such as Mg, Cu, Fe and Mn are kept at a low balanced level.

Magnesium in Plants

Roots of the plant as Mg^{++} from the soil solution absorb Mg by mass flow and diffusion. Mg content of plant ranges from 0.1% to 0.5%. The Mg present in the chlorophyll molecules is about 15–20% of the total Mg content of the plant tissues. Mg content in the grain and seeds are higher than in the other plant organs. The average uptake of Mg in crops ranges between 10–25 kg /ha /year. Mg is a very mobile element in the phloem and can be translocated from older to younger leaves. The plant tissue contains Mg^{++} in association with mobile anions such as malate and citrate and non-diffusible anion such as exalate and pectate. Root crops and legumes are heavy consumers of magnesium.

Deficiency of Mg causes typical yellowing of leaves and leaf tip necrosis in coconut palm (Brunin 1969). Manciot *et al.* (1979) described the symptoms associated with Mg deficiency in coconut palm.

Functions of Ca

Calcium occurs in plants chiefly in the leaves.

- Calcium is an important nutrient for root development and functioning. When

the Ca supply is held up, the roots turn brown and eventually die. An adequate supply of Ca stimulates the development of root hairs and encourages the development of entire root system.

- Calcium is required at various concentrations for cell division and chromosome stability. It is a constituent of chromosome, hence Ca deficiency causes chromosome abnormalities. As Ca-pectate, it is a constituent of the middle lamella of cell walls.
- Calcium enhances uptake of $\text{NO}_3\text{-N}$:
- Calcium is essential for cell elongation and division.

Functions of magnesium

- Mg plays an important role in the synthesis of the chlorophyll molecules as it occupies the central position. Mg is an essential constituent of all green plants.
- Mg favours the synthesis of carotene and xanthophyll. It activates nearly 300 enzymes mainly as cofactors. Enzymes dehydrogenase and enolases are also activated by Mg^{++} . It is involved in the synthesis of carbohydrates through the activation of the enzyme RuBp carboxylase (Rubisco), Mg^{++} is involved in the stabilization of ribosomal particle in the configuration necessary for protein synthesis. Mg^{++} is involved in the synthesis of oil in the plants.
- Mg activates formation of polypeptide chains from amino acids. Mg is needed for phyto hormone balance and reduction of nitrate.
- Mg is involved in the germination of pollen.
- Mg influences the strength of cell walls and permeability of membranes.
- Mg also increases drought resistance in plants.

FACTORS AFFECTING AVAILABILITY OF CALCIUM AND MAGNESIUM IN SOIL

- *Use of acidic fertilizers:* 100 kg of ammonium sulphate causes a loss of Ca equivalent to about 100 kg of CaCO_3 . Sulphur acidifies the soil making Ca subject to leaching. Excess use of muriate of potash also causes losses of calcium from the soil.
- *Removal by crops:* These losses are not substantial. Continued removal by crops especially under condition of acid forming fertilizer may cause its deficiency.
- *Loss by leaching:* In humid regions percolation is common. Excess water moves through the soil profile, dissolving soluble ions and carrying them into ground water. Soil layer loose soluble salts. Thus much of the adsorbed salts like Ca Mg K and Na is removed. Calcium and magnesium ions are subject to leaching in larger amounts.
- *Exchangeable ions in soil:* The amount of exchangeable cations in most soils is large. It depends upon the texture and C.E.C. of soils. Fine textured soils and those with high C.E.C. contain a larger amount of exchangeable Ca and Mg.
- *Use of liming materials:* Liming materials are the carbonates, oxides

hydroxides and silicates of calcium and magnesium. Impure CaCO_3 and dolomitic lime are mostly used as liming materials. Most Ca and Mg tests are related to the need for lime. Well-limed neutral and alkaline soils contain sufficient calcium for plant growth. If liming is not done, gypsum is needed to supply calcium. The positive effect of liming on the yield of wheat has been explained due to higher uptake and supply of calcium and magnesium besides improvement in other physical, chemical and biological properties of soils. (Sharma and Gupta, 1994)

- *Soils characteristics:* Magnesium deficiency is common in plants growing on coarse-textured acidic soils having a sandy loam, loamy sand and sand surface texture.

Calcium and Magnesium Transformations in Soil

Calcium is an important amendment element in saline and alkali soils. Calcium application helps in correcting the toxicity and deficiency of several other nutrients. The main transformations of Ca and Mg in soils are (i) solubilization and leaching and (ii) conversion into less soluble fractions by adsorption.

Solubilization and leaching of calcium and magnesium: It is affected by the following:

Soil texture: Losses are more in light -textured soils because of high permeability and percolation of rain and irrigation water.

Rainfall: As the rainfall increases the loss of Mg and Ca also increases.

Fertilizers: Acid-forming fertilizers neutralized Ca and Mg and these results in acidification. Sulphur also solubilizes Ca and Mg.

Organic matter: Application of organic matter leads to net loss of Ca and Mg from the soil.

Ferrollysis: High amounts of bases such as Ca^{2+} and Mg^{2+} may be lost from the exchange complex and leached by high amounts of cations such as Fe^{2+} and Mn^{2+} which are released following reduction of soil. This is called ferrollysis.

Conversion of calcium and magnesium into less soluble form by adsorption:

Calcium and magnesium in soil solution and in exchange complex are in a state of dynamic equilibrium. When their concentration in solution decreases, Ca and Mg coming from the exchange complex replenish this. On the other hand if their concentration in soil solution is high, there is tendency towards their being adsorbed on the exchange complex.

References and Suggested Readings

- Brunin, C. (1969). *Oleagineux* **24** : 679.
- Burstron (1968) and Jones and Lunt (1967). From Mortvedt, J.J. and Fox, F.R. (1985). Production, marketing and use of calcium, magnesium and micronutrient fertilizers, pp 455–82. *Fertilizer technology or use*. Soil Sci. Soc. Am. Proc. Madison, Wisc.
- Chopra, S.L. and Kanwar, J.S. (1966). *Journal of Indian Society of Soil Science* **14** : 69–76.
- Das, S.K. and Datta, N.P. (1973). *Fertilizer News* **18** : 3–10.
- Das, S.K. (1973). *Proceedings of International Symposium on Use of Isotopes and Radiation in Agriculture and Animal Husbandary Research*, New Delhi. 356 pp.
- Das, S.K., Ahmad, A., Tripathi, S.K. and Singh, R.D. (1994). *Journal of Indian Society of*

Soil Science **42** : 491–93.

Manicot, R., Ollagnier, M. and Ochs, R. (1979). *Oleaquinexu* **34** : 563.

Palaniappan, R. (1978). *Mysore Journal of Agricultural Sciences* **12** : 244–8.

Raj. M., Karwasra, S.P.S. and Sangwan P.S. (1994). *Journal of Indian Society of Soil Science* **42** : 152–4.

Sharma, P.K. and Gupta, J.P. (1994). *Journal of Indian Society of Soil Science* **42** : 77–80.

Stewart, J.W.G., Bettany, R.J. and Hunt, H.W. (1984). Current concepts and unsolved issues in the sulphur cycle in soil. *Proceedings of Sulphur* **84** : 700–702, (TSI-FAI Symposium, Sulphur in Indian Agriculture).

Tiwari, K.N., Nigam, V. and Pathak, A.N. (1983). *Journal of Indian Society of Soil Science* **37** : 161

Venkateswarlu, J. (1963). Ph D Thesis, P.G. School, IARI, New Delhi.

QUESTIONS

Q.1. Fill in the blanks

- i) The C:N:S ratio of soil organic matter is approximately _____.
- ii) SO_4^{2-} ions are reduced to _____ group and then incorporated into organic forms.
- iii) Single super phosphate contains approximately _____ per cent sulphur.
- iv) Elemental sulphur contains _____ per cent sulphur.
- v) The deep color of the shore of the 'Black sea' is caused by the accumulation of _____.
- vi) Amino acids methionine, cystine and cysteine contains _____ and _____ % sulphur.
- vii) Sulphur imparts resistance in plants to dehydration in the form of _____ group.
- viii) Calcium is taken up by the plants in the form of _____ ion either from the soil solution or from the clay complex.
- ix) As _____, calcium is a constituent of the middle lamella of cell walls.
- x) _____ is an essential constituent of all green plants.

Answers

- (i) 125:10:1.2 (ii) sulfhydryl-group (iii) 12 (iv) 100 (v) FeS_2 (vi) 21,27,26 (vii) SH (viii) Ca^{++} (ix) calcium-pectate (x) Magnesium

Q.2. Choose the correct answer

- i) Sulfate is mainly translocated in an upward/downward direction
- ii) In plants, more sulphur is accumulated in the grains, fruits / leaves, stem
- iii) Atmosphere / soil is important source of sulphur
- iv) Nearly 90 per cent of the total S in most non-calcareous surface soils exists as organic / inorganic forms
- v) S occurs as a cocrystallized impurity with CaCO_3 / Al Fe oxides in calcareous soils
- vi) Sulphur enhances / reduces uptake of phosphorus in plants

- vii) Sulfates tend to be unstable / stable in anaerobic environments
- viii) Sulphur oxidation is an acidifying / alkalizing process
- ix) Sulphur mineralization is favoured in soils with low / high c/s ratio
- x) Root crops and legumes are heavy consumers of magnesium / calcium
- xi) Mg^{++} / Ca^{++} is important in the synthesis of chlorophyll molecules
- xii) As the rainfall increases, the loss of Ca and Mg increases / decreases
- xiii) Application of organic matter leads to loss / gain of Ca and Mg from the soil
- xiv) Magnesium / calcium is an essential constituent of all green plants

Answers

- (i) upward (ii) grains, fruits (iii) atmosphere (iv) organic (v) $CaCO_3$ (vi) enhances (vii) unstable (viii) acidifying (ix) low (x) magnesium (xi) Mg^{++} (xii) increases (xiii) loss (xiv) magnesium

Q. 3. Define the following

- (i) Secondary nutrients (ii) Cat clays

Q. 4. Differentiate between the following

- (i) Nitrogen cycle and Sulphur cycle (ii) Occurrence of exchangeable calcium and magnesium in soil (iii) Mobility of calcium and magnesium in plants (iv) Uptake of calcium and magnesium by crops (v) Sulphur oxidation and reduction

Q. 5. Write short notes on the following

- (i) Use of elemental sulphur as a source of plant nutrient (ii) Correction of sulphur deficiencies (iii) Ferrollysis (iv) Activity of enzyme sulfatase

Q. 6. Comment on the following statements

- i) Sulphur goes through a cycle of oxidation in the soil and reduction in the plant much like the nitrogen cycle
- ii) Rocks are important natural source of sulphur
- iii) Sulphur is an important secondary nutrient
- iv) Mustard and onion have a characteristic taste and smell
- v) Sulphur is indirectly involved in detoxification of compounds unfavorable for plant growth
- vi) Onion causes tears in eyes
- vii) Crops grown on coarse-textured soils are more susceptible to S deficiency
- viii) Sulphur oxidation is an acidifying process
- ix) SO_4^- sulphur may be converted to organic sulphur forms
- x) Sulphur is responsible for photosynthesis and respiration
- xi) Sulphur is a component of many substances
- xii) The oxidation and reduction of inorganic sulphur compounds are of great importance to plants
- xiii) Saline alkali soils of arid regions have greater amounts of sulfate
- xiv) There is possibility of sulfide toxicity to wetland rice crop
- xv) Large quantities of calcium are removed by the plants from the soil
- xvi) Plants could be grown in a solution containing only a few ppm of calcium

- xvii) Calcium deficiency causes chromosome abnormalities
- xviii) Calcium concentration in the soil higher than necessary for plant growth will normally have little effect on Ca^{++} uptake
- xix) Application of ammonium sulfate may enhance Mg deficiency
- xx) Calcium and magnesium in soil solution and in exchangeable complex are in a state of dynamic equilibrium
- xxi) Calcium application not only corrects calcium deficiency but also helps in correcting the deficiency and toxicity of several other nutrients

Q. 7. Answer the following questions in brief

- i) What are secondary nutrients
- ii) Enlist different sources of sulphur which meet crop requirements
- iii) Enlist soil conditions where sulphur deficiencies commonly exists
- iv) Enlist six important sulphur bearing minerals in rocks and soils
- v) What are the important organic sulphur fractions in soil
- vi) Enlist a few bacteria responsible for reduction of sulphur compounds
- vii) What are the main fractions of calcium in plants
- viii) Enlist four calcium containing minerals along with their formulae
- ix) How does potassium fertilizers influence availability of Mg in soil
- x) Name a few common anions usually associated with Mg in plant tissues

Q. 8. Answer the following in detail

- i) Explain sulphur cycle. Also show sulphur transformations in soil plant animal system.
- ii) Enlist sulphur containing fertilizers and their mode of reaction in soil. What are the measures to be adopted to increase their potential
- iii) Give an account of the inorganic forms of sulphur
- iv) Explain factors affecting availability of calcium and magnesium in soil
- v) What are the main transformations of calcium and magnesium in soils

Q. 9. Give diagrammatic view of the following

Sulphur transformation in soil plant animal system



20

Chemistry and Availability of Micronutrients

NUTRIENTS are the chemical compounds needed for growth and metabolic activities of an organism. Nutrients are used through a chain of reactions for energetic purposes called metabolic processes. An essential element has following criteria:

It is required for normal functioning of plant- (a) deficiency of the element makes it impossible for the plant to complete vegetative or reproductive growth stages of its life cycle, (b). It cannot be substituted by other elements-the deficiency is specific to the element in question. However, in many cases it has been found that rubidium can replace potassium, strontium can replace calcium, (c) It is directly involved in nutrition and metabolism - it must be required for action of an essential enzyme system. Nicholas (1963) proposed that “functional or metabolic nutrient includes any mineral element that functions in plant metabolism whether or not its function is specific. Elements such as Cl, Si, Na and vanadium are also classified as essential according to Nicholas. In addition to this rubidium, strontium, nickel, chromium, arsenic etc. have beneficial effects on plant growth. The essentiality of elements can be studied by raising plants in distilled water or sand filled in containers made up of borosilicate glass. The nutrient solution of different elements is prepared and the relative effect is studied by comparing with control plants.

A micro-nutrient is an element that plants must have to complete their life cycles though it is required in small amounts. These elements have often been called trace elements. Some micro-nutrients are present both in plants and soils in large amounts, but only small amounts are actually required as nutrients. It is thus preferred to designate them as micro-nutrients.

MACRO AND MICRONUTRIENTS

Plant nutrients are the essential elements needed for plant growth. Plants contain many elements that are not needed for their growth. Plants absorb more than 95 elements but only 16 are known to be essential for them. Carbon, hydrogen and oxygen are obtained from air and water. The other thirteen nutrients are obtained from the soil. Plants use N, P, K, Ca, Mg, S in larger amounts and these are called macronutrients. These are found and needed in plants in relatively higher amount than micro-nutrients. The plants in the following order use their amounts:

$$N \geq P \geq K \geq Ca > Mg \geq S$$

Table 20.1. Classification of plant nutrients

Nutrient element	Uptake	Biochemical Functions	Reactions involved
C, H, O, N, S	i) In the form of CO_2 , HCO_3^- , H_2O , O_2 , NO_3^- , NH_4^+ , N_2 , SO_4^{2-} , SO_2	i) Major constituent of organic material.	i) Carboxylation
	ii) The ions from the soil solution. The gases from the atmosphere.	ii) Assimilation by oxidation reduction reactions	ii) Photolysis, iii) Amination
P, B, Si	i) In the form of phosphates, boric acid or borate, silicate from the soil solution	i) The phosphate esters are involved in energy transfer reactions	i) In plants largely bound by hydroxyl groups of sugar forming phosphate borate or silicate esters.
		ii) Absorbed as organic anions or acids.	
K, Na, Mg Ca, Mn, Cl	i) In the form of ions from the soil solution.	i) Non specific functions involving osmotic potentials	ii) Are taken up by plant as chelate complexes (except Mo) Mg Mn and Ca may also be chelated
		ii) Balancing diffusable and indiffusible anions	
Fe, Cu, Zn, Mo	i) In the form of ions or chelate from the soil solution	i) Chelated form incorporated in prosthetic groups	iii) Enable electron transport by valency charge.

The plant tissue content of the macronutrient N, for example is over a thousand times greater than the content of micronutrient Zn. However, this is not always true. The Fe or Mn content of plant tissues is sometimes as high as the content of S or Mg. Chloride occurs in plant species in comparatively higher concentrations, yet its specific role in photosynthesis is needed in minute quantities. This reveals that the content of a plant nutrient in plant organs (leaves, stems, fruits, and roots) does not give a true indication of the quantity effectively needed for physiological and biochemical processes.

NPK are called primary macronutrients, and are not usually available in large amounts in soils and are therefore added through fertilizers. Ca, Mg, S are called secondary macronutrients, are usually high in soils. These six macronutrients

Table 20.2. Micronutrient and other beneficial elements discovered so far

Element	Essentiality established by	Year
<i>Essential micro-nutrients elements for all groups of plants</i>		
Iron	E.Gris	1843
Manganese	J.S.McHargue	1922
Zinc	A.L.Sommer and C.B.Lipman	1926
Copper	A.L.Sommer, C.P.Lipman and C.McKinney	1931
Molybdenum	D.L. Arnon and P.R. Stout	1939
Boron	K.Warington	1923
Chlorine	Broyer, Carlton and others	1954
<i>Other elements</i>		
Sodium	P.P.Brownell and J.G. Wood	1957
Cobalt	S.Ahmad and H.J.Evans	1959
<i>Other beneficial elements required by a group of plants</i>		
Vanadium	Arnon and Wessel	1953
Silicon	J.C.Lewin	1962
Iodine	L.Fries	1966
Selenium	S.P.Trelease and H.M.Trelease	1938
Galium	R.A. Stunberg	1938
Aluminium	K.Tanbock	1942

make up the bulk of the plants. For example, protein includes both nitrogen and sulphur.

From a physiological viewpoint it is difficult to justify the classification of plant nutrients into macronutrients and micronutrients depending upon element concentration in plant tissues. Classification of plant nutrients according to their biochemical behaviour and physiological functions seems more appropriate. From a physiological approach plant nutrients may be divided into 4 groups (Table 20.1).

Micronutrients although essential, were produced much later. The importance of iron as a plant nutrient became evident in 1843 when chlorotic plants became green by its application. Presently, there are seven micronutrients known to be essential for plant growth and development, i.e., iron, manganese, zinc, copper, boron, molybdenum and chlorine. They take part in enzymatic reactions and regulate metabolic activities. Besides this, several other elements found in soils may affect their growth indirectly by participating in microbiological functions, i.e. valadium and aluminium affect the availability of other elements. Micronutrients and other beneficial elements discovered so far have been presented in Table 20.2.

Micronutrients in Agriculture

The target of food production can be achieved through the increase in intensity of cropping and productivity of crops per unit area per unit time. The native soil nutrients are depleted much more quickly under intensive cropping (Table 20.3). Average removal of some essential trace elements by different crops has been indicated in Table 20.4. Thus use of fertilizers, manure, soil amendments,

Table 20.3. Uptake of micronutrients by intensive cropping systems under optimum NPK rates

Cropping Systems	Economic produce (tonnes/ha)	Uptake (g/ha/year)			
		Zn	Cu	Fe	Mn
Rice-Wheat	7.07	537	1106	2616	2480
Rice-Wheat-sorghum	5.98	606	282	4683	1238
Rice-Wheat-cowpea	13.73	946	652	5982	1204
Rice-Wheat-jute	8.97	787	54	4583	972
Rice-Mustard-moong	4.43	445	208	4258	879
Maize-Wheat-cowpea					
Fodder (Ludhiana)	9.77	357	98	3237	870
Soybean-wheat	6.07	285	147	1953	615
Maize-Wheat-cowpea					
Fodder (Delhi)	7.32	482	194	3610	82

Source: Nambiar (1994)

micronutrient fertilizers, biofertilizers to maintain soil fertility becomes essential. This also necessitates a careful watch on nutrient deficiencies to maintain a technology for keeping an optimum balance among nutrients in soils. Secondary and micronutrients have not been involved in intensive cropping to the extent required. Syndromes or mysterious diseases are usually found to be due to deficiencies of one or more minor elements.

Every micronutrient has a specific role to play in plant metabolism. Deficiencies or toxicities of these elements in soil adversely affects the growth and development of crop plant. Micronutrient problems which are presently considered localized may become more serious in future occurring over extensive areas if they are not properly studied and diagnosed in time. It is universally accepted that micronutrient should be used as a basic package of fertilizers like major fertilizers. In the absence of optimum quantities of micronutrients, there is every possibility of harmful effects than benefits. Certain quantities of micronutrients, when applied to a clay soil may prove to be beneficial, whereas same quantity is toxic to sandy loam soil. The same quantity of micronutrients if applied to two different crops prove beneficial to one and toxic to other because of pH. Large quantities are required to be applied for beneficial effect in alkaline soil whereas even half of the quantities seemed toxic in acid soils. Such and like instances complicated the use of micronutrient to a greater extent.

Work done in an All India Coordinated Scheme on micronutrients in soils and plants has shown that 47, 13, 12, 10, 4 and 3% soil samples are found deficient in zinc, molybdenum, iron, boron, copper and manganese respectively in India. (Fert. News July 1986) Among the micronutrient, zinc deficiency is widespread. The soils which are coarser in texture, high in pH (>8.5 or alkali soil), high in CaCO_3 (>0.5% CaCO_3) and low in organic matter (<0.4% organic carbon) are the ones to show zinc deficiencies. High pH and high ESP characterize alkali soils. Thus, plants grown in alkali soils suffer from severe deficiency of zinc due to high pH and presence of sodium carbonate. Such soils are needed to be supplied

Table 20.4. Average removal of some essential trace elements by different crop (g / ton dry matter)

Crops	Essential trace elements					
	B	Mo	Mn	Fe	Cu	Zn
<i>Grain crops</i>						
Wheat	18	0.9	26	232	8	21
Rice	6	2.0	270	61	7	16
Maize	-	-	320	1200	130	130
Sorghum	27	1.0	27	360	3	36
Pearlmillet	27	0.8	23	264	9	22
<i>Pulses</i>						
Greengram	32	1.1	18	170	11	13
Chickpea	-	-	29	57	14	38
Pigeonpea	-	-	14	39	13	23
<i>Oil Seeds</i>						
Groundnut	9.0	1.3	39	499	5	9.0
Mustard	-	-	95	1125	17	100
Soybean	-	-	147	242	69	52
Sunflower	-	-	182	1075	38	47
<i>Cash crops</i>						
Cotton	15	0.8	14	106	8	16
Tobacco	96	0.6	132	692	11	21
<i>Tuber crops</i>						
Potato	50	0.3	12	160	9.0	9.0
<i>Fodder crops</i>						
Cowpea	53	1.3	89	260	11	17
Field vetch	29	1.1	15	71	9	15
Lucerene	36	2.6	41	420	10	21
<i>Vegetable crops</i>						
Egg plant	45	3.2	36	320	12	23
Cabbage	25	1.0	28	205	8	21

Source: Rattan, R.K. *et al.* (1999)

with nutrients particularly zinc. Moreover amendment, like gypsum exerts an antagonistic effect on the uptake of zinc by growing plants. Therefore, zinc requirement of crop is likely to be influenced by the type and amount of amendment used and the degree of soil alkalinity.

Micronutrient Deficiencies : Primary and Secondary Deficiency

Identification of deficiency symptoms is equally important to that of correcting it. Anticipation of deficiency symptoms is equally important to that of identifying them. Having done all the packages in right manner, getting low yield than also, is a sure sign of plant undergoing hidden hunger. Hidden hunger implies that starvation symptoms usually appear long after actually hunger occurs. To check the hidden hunger the only way is to adopt the balanced plant nutrition. The hidden deficiency is a situation of containment of plants by imposing self-restriction on growth and yield. Visible deficiency is an aggravated situation

limiting growth and productivity. For maximizing crop productivity, it is essential to prevent both these deficiency. There are two types of deficiencies. It is very important to know the reasons of deficiency in order to correct them effectively: Primary deficiency means low total content of the element. It may be corrected by the application of salts of micro-nutrients. Secondary deficiency means total content may be ample but due to other factors such as pH, elemental interaction, the availability of the element is limited. Correcting secondary deficiency is more complicated. Technology adopted should avoid elemental interaction. Foliar application of micro-nutrient is more suitable to avoid elemental interactions.

Diagnosis of Deficiency Symptoms and their Limitations

Visual symptoms: The visual symptoms of deficiency of micro-nutrient in crops have been identified under field conditions. Still these may not be exhibited by certain crops, which exhibit these symptoms only when they are very severe. Deficiency symptoms in such crops are not noticed and occurrence of deficiency on leaves leads to partial loss of yield.

Plant analysis: The threshold values of deficiency, sufficiency and excess have been worked out for some crops. Diagnosis by plant analysis has certain limitations. Leaf values vary depending upon stage of crops, physical and chemical nature of soil, moisture content of soil and edaphic factors. Plant analysis for total Fe often fails to reveal its deficiency status in crop plants. The active Fe (Fe^{2+}) contents isolates the chlorotic plants from green ones. The difference being expressed by the visual Fe deficiency symptoms. Thus, there is a need for establishing the relationship between active content of iron with grain and dry matter.

Soil analysis: The empirical soil analysis fails to recognize the factors and processes that regulate the availability of micro-nutrients, e.g. transformation of nutrients by soil micro-organisms, solubilization of micronutrient by mycorrhiza, antagonistic and synergistic interaction among the nutrients. These parameters should be given due consideration and researches conducted under controlled condition needs to be verified under field conditions. Then only critical limits for deficiency, sufficiency and excess can be established.

The problem of micro-nutrient deficiency becomes complex because of the masking effect of the deficiencies of other micro-nutrient. Where multiple deficiencies exist, it becomes difficult to identify the deficiency by visual observations alone. Where deficiency of particular micro-nutrient is dominant, the deficiency symptoms is characteristic.

The deficiency symptoms of micro-nutrients are commonly characterized by mottling, necrosis and chlorosis. **Mottling:** Irregularly marked spots of different colors; colors different from those of the general mass. **Necrosis:** Death associated with discoloration and dehydration of all or parts of plant organs such as leaves. **Chlorosis:** A condition in plant resulting from the failure of chlorophyll to develop caused by a deficiency of an element or nutrient. Leaves of chlorotic plants range from light green through yellow to almost white. It is a deficiency symptom due to inadequacy or deficiency of minerals like nitrogen, Mg or Fe etc. (It may also be caused by lack of light, which prevents chlorophyll formation).

Toxicity Problems of Micro-nutrients

Use of soluble salts may cause toxicity as these salts get converted into insoluble compound and may get concentrated in the rhizosphere. Toxicity of one element may cause other deficient for example, iron and manganese or calcium and boron. Determination of nutrient requirements from leaf analysis seems to be of great value.

Toxic effect produced by micro-nutrients and non essential elements can be classified into two types: (1) effects that are identical with iron deficiency symptoms and can be ascribed to the low availability or poor utilization of iron, (2) effects which are specific to the element supplied in excess. Chlorosis of the young leaves is most frequently occurring symptom of toxicity of a metal, except in case of chromium (where symptoms are produced late and in older leaves).

Micro-nutrients in Man and Animal Health

Apart from plants, micro-nutrients are also required for metabolic functions of human and animals. Plants depend on soil for micro-nutrient requirement. Plants in turn fulfil the micro-nutrient needs of man and animal. The composition of animal products consumed by man reflects the micro-nutrient content of food and feeders. (i) Zinc deficiency is common in human beings. A severe zinc deficiency is observed in malnourished children. Protein malnutrition leads to zinc deficiency. The fodder, if low in zinc, is fed to animals, the animal products will also be deficient in zinc, (ii) Deficiency of iodine causes goitre. The place which are away from sea and at high altitudes will get low iodine, because iodine originates from sea through water currents and is deposited on the land. Thus, goitre is common in Himalayan regions, (iii) Excess of fluorine in irrigation and drinking water leads to fluorosis. The dental and skeletal disorders are due to excess fluorine. The relationship of soil-plant- animal-man is vital and delicate.

Soil – a Dynamic System

- Because of numerous reactions taking place in soil, nutrients get converted into different forms, say their available and unavailable forms. Usually, it is therefore preferred to apply micronutrients in mixture.
- Specific applications are recommended on their specific need.
- In some cases, two micronutrients are more effective in their smaller amounts than if used singly for example, copper and zinc.
- In presence of micronutrients, there is a greater absorption of other minerals. Boron affects uptake of calcium. Calcium in turn affects the uptake of all other elements.

ROLE OF MICRONUTRIENTS

Micro-nutrients have specific and precise role. It can be summarized as below:

- Some micronutrients function in the enzyme systems of plants. Enzyme molecule may contain boron and molybdenum (anion forming elements) as part of their structure. Cation forming elements such as copper serve as coenzymes that activate an enzyme.

- Micro-nutrients function in oxidation reduction processes of plant metabolism. Thus iron, copper and manganese may enter into oxidation-reduction reactions (as these elements can change their valencies).
- Some micro-nutrients are necessary in the production of chlorophyll.

Role of Zinc

Zinc is a metal component of a series of enzymes: It is required for the formation of certain microbial enzymes. The metal has shown to be a specific inducer of pyruvic carboxylase in *Rhizopus nigricans* and of alcohol dehydrogenase. Zinc plays an important role as a constituent of alcohol dehydrogenase and galactose oxidase in yeasts and moulds respectively.

Enzyme activator: It activates enzyme carbonic anhydrase and dehydrogenase.

Deficiency of zinc restricts RNA synthesis and protein synthesis: Zinc plays a role in photosynthesis and nitrogen metabolism. As in case of copper, the effect of zinc deficiency on photosynthesis is found even in apparently normal green leaves of zinc deficient plants.

Zinc is involved in auxin production: Zinc plays a role in regulating the auxin concentration in plants.

Role of Copper

Copper is associated with metal protein: Polyphenol oxidase, ascorbic acid oxidase and tyrosinase have been held to be terminal oxidases in respiration. They catalyse the actual oxidation in the last stage of aerobic oxidation in which hydrogen is removed from reduced coenzymes produced during the Krebs's cycle.

Presence in cytochrome oxidase: Several plant enzymes contain copper. These are polyphenol or catechol oxidase, tyrosinase, laccase and ascorbic oxidase. These are all enzymes, which bring about the oxidation of organic compounds by means of molecular oxygen.

Presence in chlorophyll: Copper is concerned with the oxidation of iron in the plant. Copper is strongly bound to the protoplasm.

Role of Iron

Role in enzyme system: Iron plays a key role in enzyme systems (Haem enzyme, catalase, peroxidase and cytochromes). Iron is a constituent of porphyrin compounds-cytochromes, haem and haem enzymes and other functional metallic proteins. The cytochromes play an important role in oxidative and phosphorylations during the respiratory electron transport and photosynthesis respectively.

In leguminous plants: The haemoglobin of the leguminous root nodules-laghaemoglobin contain iron as an essential nutrient.

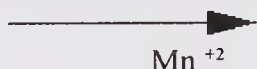
Constituent of enzymes: Iron is a constituent of non-haem enzymes ferredoxin, regulates oxidation reduction reactions. The iron containing protein ferradoxins with a very long oxidation-reduction potential plays an important role in the reduction of CO₂, atmospheric nitrogen and sulphate.

Nitrogen assimilation: It plays an important role in photosynthesis, nitrogen assimilation. It has some role in the synthesis of chlorophyll precursor and proto

porphyrin. Being a constituent of ferradoxin, iron is involved in the nitrogen fixation by a diverse group of micro organisms.

Role of Manganese

Tricarboxylic acid cycle: Manganese has a primary role in the tricarboxylic acid cycle in oxidation and reduction reactions i.e. malic enzyme and isocitrate dehydrogenase.



Activates a number of enzymes: It is known to activate a wide variety of enzymes concerned in cellular oxidation-reductions (oxidoreductases), hydrolysis (hydrolases), group transfer (lyases) and joining together of 2 molecules coupled with the breakdown of phosphate bonds in ATP or a similar phosphate.

Acts as an autocatalyst: Isocitrate dehydrogenase, malic dehydrogenase, glycocyamine, D-alanyl synthetase of micro organisms are important Mn requiring enzymes.

Involved in water splitting reaction during photosynthesis: Manganese is also essential for nitrogen metabolism. It is involved in chlorophyll synthesis by regulating the lipid content in the thylakoid membrane.

Involved in carbondioxide assimilation: It plays a role in photosynthetic O_2 evolution, carbohydrate and protein synthesis.

Cell elongation: It has been indicated that Mn is important for the growth of lateral roots by its role in cell elongation.

Involved in nitrogen metabolism: As a constituent of hydroxylamine reductase, which catalyses the reduction of hydroxylamine to ammonia which is later metabolized into soluble organic nitrogen compounds and proteins. Mn may play an important role in nitrogen metabolism.

Role of Boron

Physiological activities: Boron is required for proper development and differentiation of tissue particularly vascular elements. It is involved in the vital physiological activities of the plant. Boron increases the cell wall thickness by forming certain complexes.

Reproductive phase: Boron is involved in the reproductive phase of plant. Boron functions in cell maturation by regulating the formation and lignification of the cell wall. Boron increases the pollen grain producing capacity of anthers and pollen grains viability. Boron deficiency creates sterility and malformation. Boron deficiency in plants exhibits necrosis and disorganization of tissues.

Transport of carbohydrates: It is involved in carbohydrate metabolism, particularly in the translocation of photosynthates-the sugar. Boron forms complexes with sugar for easy transportation through cellular membrane.

Cell wall synthesis: Boron is involved in the cell wall synthesis through N-base utilization. It is also involved in the synthesis of proteins. It inhibits IAA oxidation.

Role of Molybdenum

Assimilation of nitrogen: Molybdenum has been shown to be required for nitrogen fixation by nitrogen fixing agents such as *Azotobactor*, *Clostridium* etc.

Component of nitrate reductase and nitrogenase: Molybdenum is a constituent part of the enzyme nitrate reductase and nitrogenous concerned with the reduction of nitrate to nitrite in both micro-organisms and higher plants.

Synthesis: Molybdenum is needed in the synthesis of ascorbic acid.

Physiological activity: Molybdenum makes iron physiologically available within the plant.

Antidote: Molybdenum is an antidote of excessive copper, manganese and zinc.

Role of Chlorine

Photosynthesis and enzyme activation: Some of the enzymes activated are involved in starch utilization, which affects germination and energy transfer. These functions require a small amount of chloride (Cl^-).

Transport of other nutrients: Chloride aids in the transport of nutrients such as K, Ca and Mg. Its role is to maintain electrical charge balance.

Water movement in the cell: Concentration of Cl^- in the cells aid in the movement of water into cells and retention of that water. This is especially important under moisture stress conditions.

Stomatal activity: Both K and Cl are involved in the movement of guard cells that control opening and closing of stomata on leaf surfaces. High concentrations of K and Cl cause the guard cells to swell, closing the stomata and controlling water loss.

Nitrification inhibitor: Under certain conditions, chloride may limit the conversion of ammonium nitrogen into nitrate nitrogen in the soil. Presence of chloride in the soil may then aid in plant utilization of ammonium nitrogen, which may positively affect plant nutrition and health.

Disease suppression: Many crop diseases particularly of small grains are temporarily suppressed by chloride. Fungi cause many of these diseases, in both root and leaf.

Reproductive development: Small grain crops grown with adequate chloride tend to form heads earlier and complete head emergence sooner than low chlorides plants.

CHELATED NUTRIENTS

Chelate

The term chelation is derived from the Greek word Chela which means, Claw. The commonly used words such as chelates, chelated complex or chelated compounds refer to organometallic molecules of varying size and shapes in which organic part bind with metal cation in a ring like structure. A chelated atom is one that is bound to an organic compound by two or more bonds in a ring structure. Thus a stable complex is formed which is highly soluble in water and is relatively stable to changes in pH. The advantage of chelated micronutrient can be shown

with iron, for example, ferrous sulphate is soluble in water, thus as ferrous sulphate dissolves it ionizes. The ferrous iron is soon oxidized and precipitated as ferric hydroxide (insoluble). Iron chelate is also soluble in water, but it does not ionize. The iron is held in a soluble form and is readily available for root absorption.

Occurrence of Chelates

The process of chelation is seen in nature, in soils, in plants and inside the human body. Naturally occurring chelates belong to haem group (iron porphyrin). Iron is bound to nitrogen of two pyrrole rings by co-ordinate bonds and to the two remaining N-atoms of the other two-pyrrole rings of the porphyrin structure by valence bonds. The structure of chlorophyll is similar to haem structure. Chlorophyll, the green pigment in leaves is a chelate of magnesium. Hemoglobin, red substance in blood can be seen as iron chelate. The various organic acids like humic acid, fulvic acid, amino acid form chelates with cations.

Types of Chelates

There are natural as well as synthetic chelating agents used to chelate the metallic ion. Some natural chelating agents are lignosulphonates, phenols, polyflavonoids. Common synthetic chelating agents are EDTA, HEDTA, DTPA, EDDHA etc.

Qualities of Chelate

- The chelate should be soluble and stable. Stability of metal chelate bond affect the availability of the nutrient to plant. Chelating agents have different stabilities. EDDHA is considered to be stable throughout the pH range of 4 -10.
- It should not get converted into insoluble forms.

A good chelate will protect the nutrient cation till the time it is delivered to the plant root and not to release it prematurely for re-fixation in the soil. There is a wide range of effectiveness and all types of chelates of a given nutrient are not equally effective.

Inorganic salts and chelates

Inorganic salt	Chelates
Inorganic salts are easily available and much cheaper.	Chelates are not easily available. They are costly.
They are not so effective to correct a single nutrient deficiency.	Chelates can be best used when there is a single nutrient deficiency. They can be used in problematic soils.
They are applied as basic application of nutrients.	They cannot become basic application of nutrients.
The universal principle of balanced plant nutrition means application of all essential elements. To achieve this, the best source of micro-nutrient is inorganic salts.	Balance plant nutrition is not possible through chelation, as all elements can not be chelated.

Clays, being negatively charged attract and immobilise positively charged metal ions. Clays lock up the micronutrient. This stops movement of micronutrient metals towards the root system.

With non-chelated salts of micronutrient, the micronutrient must be placed among the root zone so that it may be effectively utilized by plants.

If the micro-nutrient metal is not chelated, the mobility of micronutrient is much less. In such cases, proper placement of micro-nutrient becomes essential.

Residual phosphate inactivates the natural micronutrients content of soils. This creates shortage of micronutrients. Besides, this other major nutrient also limits the availability of essential micronutrient. Cost / benefit ratio is less.

In a chelated form, the micronutrient metal is negatively charged. This allows free movement of the micro-nutrient in soil solution which is rapidly taken up by root system.

Chelated micro-nutrients being mobile move in soil solution for efficient uptake by the plant. For example, nitrogen as ammonia is a positive nutrient and is rapidly adsorbed by the soil. When soil bacteria convert ammonia to nitrate form, nitrate being negative form is able to move with the soil solution to the root zone. If it has not been so, the use of ammonia could be inefficient.

A micro-nutrient must be converted to a negative form. A chelating agent does so. As the plant root remove water from the nearby soil, stored soil moisture move in. The moisture also brings the chelated micronutrient together. Chelated micronutrients are most beneficial in terms of mobility and response. Cost / benefit ratio is more.

Mechanism of Chelate in Soil

The organic radical is negatively charged and forms covalent bonds with the positively charged metal cation. Thus, only some nutrients can be chelated. The nutrients, which can be chelated, are Ca^{++} , Mg^{++} , Cu^{++} , Mn^{++} , Fe^{++} and Zn^{++} . The nutrients like boron, molybdenum can not be chelated. The nutrient is held as long as the grip is tight. Nutrients can be freed as soon as the grip is loosened. Synthetic agents like organic acids by loosing an atom of H from COOH develop negative charges replaced by the positively charged cations. Chelation in the vicinity of roots plays a major role in the availability of nutrients. Chelated micronutrient allows the metal (having acquired negative charge) to move to the root zone for rapid and efficient plant absorption.

Limitation in Use of Chelates

- Cost factor: Minerals and Metal Trading Corporation of India fixes prices of metallic constituents utilised for fertilizers manufacture. For example, a price of Rs 75,000/= per tonne has been fixed for metallic zinc. The mere cost of Zinc Sulphate heptahydrate is Rs 15, 750/= per tonnes. In addition to this, other cost of manufacture like labour, other raw materials used are also involved, which make it still costlier (*Fertilizer News, January 1993*).
- Danger of impurity: Zinc Sulphate manufacturers use Zinc / Brass scrap as their primary zinc source, but this has its own dangers, like toxic impurities of lead and cadmium. High impurities of lead can stunt growth and diminish intelligence in children. Cadmium can cause liver diseases.
- Technical problem: The subsidy of 25% on $ZnSO_4$ included in IPRD / SFPP program is not sufficient (*Fertilizer News, January 1993*).

FACTORS AFFECTING AVAILABILITY OF MICRONUTRIENT CATIONS AND ANIONS

The trace element content of a soil may be affected because of following factors:

Nature of Soil

The micronutrients from the standpoint of soil chemistry can be put in three groups:

- Heavy metal cations – Co, Cu, Zn. They are held on soil surface.
- The divalent cations – Fe, Mn, which are held less strongly on soil surfaces. These cations being oxidized to higher valence states can form insoluble oxides and are not easily leached.
- Anions like Boron and Molybdenum (MOO_4^{2-}). Boron held in soil is present as resistant mineral, tourmaline. Under acidic conditions, molybdenum combines with sesquioxides and clay minerals. Biological cycle also plays a role in conserving both these elements (boron and molybdenum) from leaching.

Influence of parent material

- The rocks from which the parent material was derived. For example,
 - Soils formed from basic rocks are likely to have high content of Co, Ni, Cr, Mn and Cu while soils derived from acid rocks such as granites may be relatively low in these elements.
 - Soils derived from argillaceous shales and slates tend to be naturally rich in trace element. On the contrary, those developed from sandstone and related rocks tend to be poor in their trace element content.
 - The influence of parent material is more pronounced during the early stage of soil development. The rate of weathering of the individual constituent minerals of igneous rocks governs the rate at which the elements contained in them become available. Table-20.5 indicates relative stability of the common minerals of igneous rocks and the trace elements with which they are associated.

Influence of Processes of Weathering

It involves the processes of weathering to which soil forming materials were subjected. Most of important trace elements such as Zn, Mn, Co and Cu occur in easily weathered constituents of igneous rocks as indicated in Table 20.5. Trace element content of igneous and sedimentary rocks and the factors governing their distribution account for the differences in different parent materials (Table 20.6). Physical weathering leads to the formation of sediments containing original minerals. Chemical weathering involves a solution process and governs the differentiation in sedimentary rocks (most of the present surface of soil is contributed through sedimentary rocks).

Shales, which constitute 80% of the total sedimentary rocks, are important from the soil point of view. Igneous and sedimentary rocks when subjected to pressure and heat result in their crystallization, and some adsorbed ions become incorporated in the crystal lattice. For example, boron is incorporated in a resistant mineral, tourmaline. The distribution of trace elements from soil parent materials enables to anticipate the total content of trace element with some degree of accuracy in young soils than those which have undergone little weathering.

Table 20.5. Relative Stability of the Common Minerals of Igneous Rocks and the Trace Elements with which they are associated

Stability	Mineral	Major constituents	Trace constituents
Easily weathered	Olivine	Mg, Fe, Si	Ni, Co, Mn, Li, Zn, Cu, Mo
	Hornblende	Mg, Fe, Ca, Al, Si	Ni, Co, Mn, Sc, Li, V, Zn, Cu, Ca
	Augite	Ca, Mg, Al, Si	Ni, Co, Mn, Sc, Li, V, Zn, Pb, Cu, Ca
	Biotite	K, Mg, Fe, Al, Si	Rb, Ba, Ni, Co, Se, Li, Mn, V, Zn, Cu, Ca
	Apatite	Ca, P, F	Rare earths, Pb, Sr
	Anorthite	Ca, Al, Si	Sr, Cu, Ga, Mn
	Andesine	Ca, Na, Al, Si	Sr, Cu, Ga, Mn
	Oligoclase	Na, Ca, Al, Si	Cu, Ga
	Albite	Na, Ca, Al, Si	Cu, Ga
	Garnet	Ca, Mg, Fe, Al, Si	Mn, Cr, Ga
Moderately stable	Orthoclase	K, Al, Si	Rb, Ba, Sr, Cu, Ga
	Muscovite	K, Al, Si	F, Rb, Ba, Sr, Ga, V
	Titanite	Ca, Ti, Si	Rare earths, V, Sn
	Ilmenite	Fe, Ti	Co, Ni, Cr, V
	Magnetite	Fe	Zn, Co, Ni, Cr, V
	Tourmaline	Ca, Mg, Fe, B, Al, Si	Li, F, Ga
	Zircon	Zr, Si	Hf
	Very stable	Quartz	Si

Source: Mitchell, 1965

Table 20.6. Micro-nutrients in soils and rocks (mg kg⁻¹)

Element	Earth's crust	Basic rocks	Acid rocks	Sedimentary	Soils
B	3–10	10	15	12	10
Mn	1000	2000	600	670	850–1000
Fe	50000	86000	27000	33000	38000
Co	23–40	45	5	23	8
Cu	45–70	140	30	57	20
Zn	65–80	130	60	80	40–58
Mo	1–3	1.4	1.9	2	1–2

Textbook series in Agricultural Chemistry, Soil Science: Genesis-Survey Classification

Micro-nutrient Variations in Soils

Variations in the content of most trace elements in soils are far greater than variations in macronutrients. The total content of trace element may vary thousand folds. The total content is a fairly good indication of trace element content of a soil. This also helps in predicting the excess or deficiency of biologically important trace elements. The presence of organic matter on surface horizons, cropping and cultivation regulate the distribution and mobility of micronutrient cations. There are significant differences in trace element content of freely drained and poorly drained profiles irrespective of their parent material.

Effect of Clay Minerals, Iron, their Oxide and Organic Matter

The trace elements released during the course of weathering may be locked up in the crystal lattices of the clay minerals and thus become relatively unavailable. On the contrary, if they are adsorbed at exchange sites of clay minerals, they become available fairly easily. In presence of organic matter, trace elements may be adsorbed as organic-mineral complexes.

Clay mineral bind trace elements with varying degree of forces. Different binding forces account for variation in the extraction rate of different trace element cations by different reagents. Trace elements are readily adsorbed by clay minerals but displaced with difficulty. The relative ease of displacement is: Li > Na> Mg > Ca> Zn > Co > Cu. (Li can be easily displaced and Cu is displaced with difficulty.

A few trace elements like Mo, B and V when displaced by weathering appear as complex anions. Calcium or organic complex may bind these anions. Molybdate is less strongly bound than phosphates or sulphates.

During soil development trace elements may become associated with iron and other oxides. The presence of these oxides around the surface of clay minerals restricts the adsorption of cations and anions by these minerals. The oxide layer coats particles of all size fractions and most elements may be extracted.

Humic and fulvic acids in organic matter play an important role in nutrient cation fixation. The greater acidity of fulvic acid is due to the presence of more COOH groups, with which major part of cation exchange capacity of organic matter is associated.

One of the criteria of availability of trace elements is their uptake by plants. Different plant species and varieties differ in their uptake of trace elements.

Micronutrients and Plant Growth

The micronutrients are present as part of the exchange complex or in soil solution. The availability of these micronutrient contents depends on the composition of the minerals. The availability to plant growth is influenced by the factors: 1. Clay contents 2. Free calcium carbonate content 3. Organic matter content 4. Soil pH 5. Salt concentration 6. Fertilizer doses 7. Soil moisture status 8. Climatic conditions 9. Crops and their varieties.

Factors Affecting Availability of Boron, Copper, Iron, Manganese, Zinc, Molybdenum and Chlorine

These factors will be discussed in detail while reviewing individual micronutrient cation in further discussion.

Boron

Boron is a non-metal. It occurs as non-ionized H_3BO_3 in soil solution, but as $\text{B}(\text{OH})_4$ at pH greater than 8.5. Boron has three valencies. Boric acid is a very weak acid and in aqueous solution at pH 7, it occurs as undissociated boric acid. At higher pH, boric acid accepts hydroxyl ions from water, thus, forming tetrahedral borate ions.

$\text{B}(\text{OH})_3 + 2\text{H}_2\text{O} \rightleftharpoons \text{B}(\text{OH})_4 + \text{H}_3\text{O}^+$. The most prominent boron mineral in soils is tourmaline. In soils, boron has four major groups: 1) in primary rocks and minerals, 2) combined with soil organic matter, 3) adsorbed on colloidal clay and hydrous oxide surfaces, much as in phosphorus and 4) as boric acid (H_3BO_3) or $\text{B}(\text{OH})_4$ ion in soil solution.

Soil texture: Higher clay content decreases boron availability. Clay retains boron more effectively than sands. Thus plants will take up much larger quantity of boron from sandy soils than will from fine textured soil at equal concentration of water-soluble boron.

pH and liming: Boron availability decreases as the pH increases, as a result of formation of $\text{B}(\text{OH})_4$. Moderate liming depresses boron availability and uptake. It is therefore, practiced in soils containing high boron. High pH resulting from heavy liming of soils may encourage organic matter decomposition and release of boron.

Organic matter: Organic matter content increases the boron availability by (i) Preventing its leaching loss (ii) Brings about its accumulation in surface soil (iii) Lowers the effect of rising pH.

Boron is more available in surface soil as compared to sub surface soil. This is because of greater quantities of organic matter present in the surface soils. Hence, application of organic materials to soils can raise the concentration of boron in the plants.

Inter relationship with Other Nutrients

Calcium: When plants have low calcium supply their tolerance to boron deficiency decreases. When calcium nutrition is high, there is a greater requirement for boron. The occurrence of free calcium ions in alkaline soils restricts boron availability. Thus, Ca/B ratio in leaf tissues has been used to assess the boron

status of crops.

Potassium: Increased rates of potassium accentuate boron toxicity (at high levels of boron). On the contrary, when boron nutrition is low, increased rates of potassium may accentuate boron deficiency symptoms.

Copper

The common forms of soil copper are 1). In the soil solution (ionic and complexed), 2). On normal exchange cation exchange sites of clays and organic matter-held electrostatically in response to coulombic forces, 3). Co-precipitated in soil oxide materials, 4). On specific adsorption sites- when held in this form copper cannot be removed by the reagent normally used for replacing exchangeable ions and 5). In biological residues and living organisms. Copper is very tightly bound in soil. There is, however, a significant 'pool' of diffusable copper, in the form of organic complex which is in equilibrium with very low level of Cu in soil solution.

Texture: Cu deficiency usually occurs in sandy and gravelly soils. An increase in available Cu with an increase in the finer fraction of soil has been reported.

Soil pH: The mobility of Cu in soil solution often decreases with increasing pH and its supply is correspondingly reduced because of greatly diminished solubility and increased sorption on mineral colloidal surface. The general effect of increasing adsorption with increasing pH is believed to be due to (i) an increased generation of pH dependent sites on the soil colloids. (ii) Reduced competition with hydrogen ions (iii) change in hydrolysis status of Cu in solution.

Interrelations with other elements: Application of nitrogen fertilizer can aggravate copper deficiencies. NPK fertilizers have been implicated for greater incidence of copper deficiencies. The occurrence of copper deficiencies following the use of acid forming fertilizers may be due to increased aluminum levels in soil solution. High concentration of zinc and aluminum in soil solution depress absorption of Cu by plant roots and may intensify Cu deficiency. Both phosphorus and iron have been found to restrict copper absorption by plants. A reverse relationship between Mo and Cu has been observed. The accumulation of Cu occurred in molybdenum deficient leaves and vice versa.

Incorporation of crop residues: It is possible that the large amount of sulphur released during decomposition of crop residues may immobilise Cu in soil solution. Reduction in effectiveness of fertilizers Cu include, (i) Chemical reactions of Cu with organic compounds and other substances originating from decomposition of straw, (ii) Competition for available copper by stimulated microbial populations. (iii) Inhibition of root development and ability to absorb copper.

Plant factors: Some plant species exhibit Cu deficiency more frequently than others. Crops that are highly responsive to copper include wheat, rice, citrus and onion. On the other hand, crops with greatest apparent tolerance to low Cu are beans, peas and potatoes. There are genotypic differences in the Cu nutrition of plants. Some of the mechanisms resulting in the genotypic differences are Cu absorption by roots, root length per plant, longer root hairs, root exudates, change in redox potential, more efficient transport of Cu from roots to shoots, lower tissue requirement.

Iron

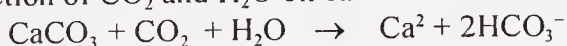
It is interesting to know that in the case of iron nutrition of plants, there is one peculiarity that the limitations of growth under conditions of iron deficiency is usually a consequence of the quality rather than the quantity of iron within the plants. Iron has a tendency to become unavailable within the plants. Generally, clay contains more of the fine sized particles of iron. The basis of iron deficiencies of plants is one of soil and environmental conditions impairing the availability of soil iron.

Iron imbalance

It may occur due to:

(a) Accumulation of copper in soils after long years of application in sprays and fertilizers (b) iron Chlorosis: when crops are grown on soils high in Mn (c) iron deficiency may occur in soils because of a low ratio of Fe/Cu+Mn in the plants.

Effect of pH, bicarbonate and carbonate: (a) Fe deficiency is common on high pH and calcareous soils in arid regions, but it may also occur in acid soils that are low in iron, (b) Solubility of iron reaches to minimum between pH 7.4-8.5. It is between this pH range in soils that iron deficiencies usually occur. Significance of high pH on iron availability is obvious when it is realized that Fe^{3+} and Fe^{2+} activities in the soil solution decrease 1000-fold and 100-fold respectively for each unit increase in pH, (c) Irrigation waters and soils high in bicarbonate (HCO_3^-) may aggravate iron deficiencies. The undesirable effect of HCO_3^- may be due to the high pH levels accompanying its presence and (d) The pH of the most soils containing CaCO_3 falls in the range 7.3 to 8.5, which coincides with greatest incidence of iron deficiency and lowest solubility of soil iron. Similar conditions of pH and iron availability result from the presence of calcite and dolomite in soils. Bicarbonate can be formed in calcareous soils by the following reaction of CO_2 and H_2O on calcite.



Excessive water and poor aeration: (a) Accumulation of CO_2 will occur when soils are wet and poorly drained. Consequently, any compact heavy textured soil that is calcareous and basic in reaction is iron deficient. (b) Iron chlorosis is associated with cool, rainy weather when soil moisture is high and soil aeration poor.

Organic matter: (a) Additions of organic matter to well drained soils have produced varying effects on iron availability. Organic materials such as manure may supply chelating agents that add in maintaining the solubility of micro-nutrients. (b) improved soil structure resulting from applications of organic manure should increase iron availability because of better soil aeration. (c) presence of organic matter can have a profound influence on iron solubility in waterlogged soils. Iron reduction was greatly accelerated by the addition of organic matter, and the longer the period of submergence, the greater the amount of soluble plus exchangeable iron.

Interrelationships with other nutrients: (a) Excesses of essential nutrients such as Co, Cu, Mn, Mo, Zn and P will encourage iron deficiency. (b) Two iron-

phosphorus relationships are known in plants. First, high P level usually aggravate iron deficiency through some kind of inactivation reaction. The second relationship indicates that plant can be more tolerant of low iron when phosphorus is also low. (c) Plants receiving NO_3^- are more likely to develop iron chlorosis than those nourished with NH_4^+ . Nitrate uptake leads to an alkalization effect in the root zone and in the plant, a condition that can markedly lower iron solubility and availability. Iron solubility and availability are favored by the acidity that develops when NH_4^+ is utilized by plants (d) Deficiencies of potassium or zinc can disrupt movement of iron within plants. Lack of either of these two nutrients causes iron to accumulate in stem nodes of maize.

Plant factors: Differential responses to iron deficiency occur in a wide variety of plants. The ability of plants to absorb and translocate iron appears to be a genetically controlled adaptive process that responds to iron deficiency or stress. Roots of iron efficient plant alter their environment to improve the availability and uptake of iron. Some of the biochemical reactions and changes enabling iron efficient plants to tolerate and adapt to iron stress are:

- Excretion of H^+ ions from roots.
- Excretion of various reducing compounds from roots.
- Increases in the rate of reduction (Fe^{3+} to Fe^{2+}) at the root surface.
- Organic acids increase in the root saps.
- Adequate transport of ions from roots to tops.
- Less accumulation of phosphorus in roots and shoots even in the presence of high phosphorus in the growth medium.

Iron efficient varieties should be selected for conditions where iron deficiencies are likely to occur.

Sensitivity of crops to low level of available iron in soil

Sensitive	Moderately tolerant	Tolerant
Citrus	Barley	Potato
Fruit tree	Cotton, oats	Sugarbeet
Vegetables	Rice, wheat	

Manganese

Manganese has been found to exist in soils as water soluble, exchangeable and higher oxides of manganese, which exist in equilibrium in soils. The usual forms of manganese in soils are various oxides and hydroxides. They occur as coatings on soil particles, deposited in cracks and veins, and mixed with iron oxides and other soil constituents in nodules. Individual crystallites are small and have large surface area. The principal ion species in solution is Mn^{2+} . MnSO_4 (aq), MnHCO_3^+ and MnOH^+ are other minor species present. Dissolved Mn^{2+} in soil solution is of direct importance to plants since they obtain their entire requirement in this form. Manganese in soil solution is greatly increased under acid soils, Mn^{2+} solubility can be sufficiently great to cause toxicity problems to sensitive species. The occurrence of manganese deficiency may be because of

intensive leaching of soluble Mn.

Imbalance of heavy metal ions: High level of Cu, Fe or Zn in the growth medium will impede Mn uptake by plants.

Effect of pH and carbonates: Mn^{2+} concentrations are sensitive to pH. Management practices that change soil pH will also greatly influence Mn^{2+} availability and uptake. Liming very acid soils resulted in a three - fold decrease in the amount of exchangeable Mn^{2+} in the soil. It also resulted in a two - fold decreases in the Mn content in the plant.

Low Mn^{2+} availability in high pH and calcareous soils and in over limed, poorly buffered, coarse textured soils can be overcome by acidification through the use of acid forming nitrogen or sulfur materials. High pH favours the formation of less available organic complexes of manganese. Activity of soils micro organisms which oxidize soluble manganese to unavailable forms reaches a maximum near pH 7.

Excessive waters and poor aeration: Soil submergence and waterlogging lower redox potential and increase the amount of soluble Mn^{2+} in soils. This is true in acid soils high in active manganese. As soluble Mn^{2+} concentration increases under submerged condition, there is a corresponding decline in O_2 levels.

Manganese availability can be increased by poor aeration in compact soils and by local accumulations of CO_2 within root masses. The resulting low redox conditions will render Mn more available without appreciably affecting redox potential or pH of the bulk soil.

Organic matter: Availability of Mn^{2+} can be affected in several ways by the presence of organic material. The low availability of Mn in basic soils, high in organic matter is attributed to the formation of unavailable chelated Mn^{2+} compounds. It may also be held in unavailable organic complexes in peat and muck soils.

Additions of certain neutral organic materials such as compost and straw have increased Mn^{2+} in water soluble, water soluble + Exchangeable, exchangeable and easily reducible fractions.

Interrelationships with other nutrients: Addition of physiologically acidic nitrogen materials such as NH_4Cl , $(NH_4)_2SO_4$, NH_4NO_3 , $NH_4H_2PO_4$ and $CO(NH_2)_2$ to the growth medium will enhance plant uptake of Mn^{2+} . Neutral chloride containing salts including KCl, NaCl have increased the Mn^{2+} concentration of plants and level of Mn in acidic soils.

Phosphate fertilization also has been reported to both enhance and decrease Mn^{2+} availability.

Seasonal and climatic factors: It is believed that wet winter weather favours the presence of Mn^{2+} whereas warm, dry summer conditions encourage the formation of less available oxidized forms of Mn^{2+} . It has been indicated that dry weather increased manganese deficiency or aggravated this nutritional problem particularly in fruit trees.

Plant factors: The differences in response of Mn-efficient and Mn-inefficient plants are believed to be due to internal factors rather than to the effects of the plants on the growth medium. Reductive capacity at the root may be the factor restricting uptake and translocation of Mn^{2+} . There may also be significant

differences in the amounts and properties of root exudates generated by plants. Dissimilarity between Mn-efficient and Mn-inefficient oat plants has been attributed to calcium substituting for Mn at non-specific sites in Mn-efficient plants, thus freeing adequate Mn for essential reactions. It is possible that some or all of the plant characteristics possessed by iron efficient plants may similarly influence manganese uptake in plants tolerant of manganese stress.

Sensitivity of crops to low levels of available manganese in soil

Sensitive	Moderately tolerant	Tolerant
Citrus, oats, onion sugarbeet, wheat	Barley, cotton, rice, wheat	Barley, soybeans, vegetables wheat

Zinc

The igneous rocks basalt and granite contain on the average 100 and 40 mg kg⁻¹ of zinc respectively. Among sedimentary rocks, shales contain more zinc (95mg kg⁻¹) than either limestone. (20 mg kg⁻¹) or sandstone (16 mg kg⁻¹). Sphalerite (ZnS), smithsonite (ZnCO₃) and hemimorphite (Zn₄ (OH)₂ Si₂O₇ H₂O) are common zinc containing minerals. Zinc has a strong tendency to combine with sulfides and it occurs most frequently in the lithosphere as sphalerites. The forms of zinc in soils considered to influence in varying degree its supply to plants are water soluble Zn²⁺, exchangeable Zn²⁺, adsorbed Zn²⁺ on surfaces of clay, organic matter, carbonates, and oxide minerals; organically complexed Zn²⁺ and Zn²⁺ substituted for Mg²⁺ in the crystal lattices of clay minerals. Most of the zinc in many soils is located in ferromagnesian minerals such as augite, hornblende and biotite. The occurrence of Zn²⁺ in these minerals is due to its isomorphous replacement of some of the original Fe²⁺ and Mg²⁺. The oxidation state of zinc in soils is exclusively Zn²⁺. Several zinc hydrolysis species exist in solution with Zn²⁺ predominating at soil reactions below pH 7.7. Above this pH, ZnOH⁺ becomes the most abundant species until it is supplemented by Zn(OH)₂ at pH 9.1. Complexes with nitrate chloride and phosphate can form, but with the exception of ZnHPO₄ in solution are considered insignificant. Plants take up zinc as the Zn²⁺ ion, and mobility of this ion in soil has an important bearing on proper nutrition of plants. Diffusion is the dominant mechanism for transporting Zn²⁺ to plant roots.

Soil pH

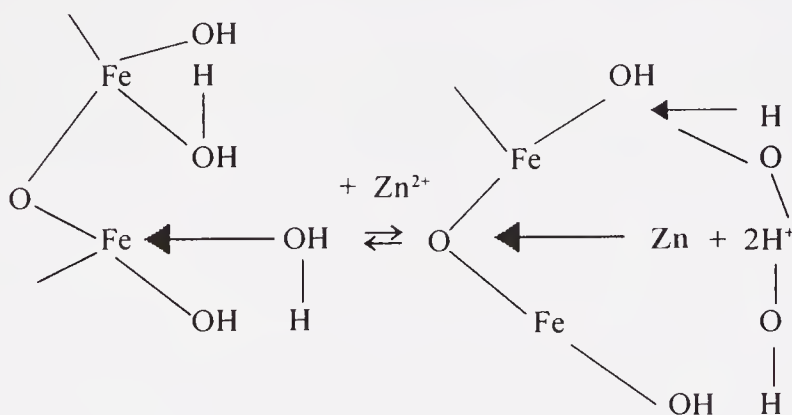
The availability of soil zinc to plants decreases with increase in soil pH, as would be expected by the sensitivity of Zn²⁺ solubility to pH. Most pH induced zinc deficiencies occur within the range 6.0 to 8.0 and calcareous soils are prone to this nutritional problem. It should be noted that not all-basic soils are deficient in zinc because of mechanisms such as chelation of Zn²⁺ by naturally occurring organic substance, which may compensate for low solubility of Zn²⁺ at high pH. At high pH, zinc forms insoluble compounds such as Zn(OH)₂ and ZnCO₃ which can reduce available zinc in soils to lower levels. The drastic decline in Zn²⁺

solubility with increasing pH is the overruling factor.

Liming acid soils especially that low in zinc will reduce uptake of Zn^{2+} . This depressive action is usually attributed to the effect that increasing pH has on lowering Zn^{2+} solubility. It is possible, however, that some Zn^{2+} could be adsorbed on the surface of freshly added particles of liming agents such as CaCO_3 . With increasing pH, zinc adsorption by hydrated Al_2O_3 and Fe_2O_3 is increased. Adsorption of Zn^{2+} by organic matter is also influenced by pH. The amount of Zn^{2+} complexed by humic acids increases with rising pH. The stabilities of zinc-organic complexes increase up to a point with increasing pH, after which the complexes break up and hydroxides form.

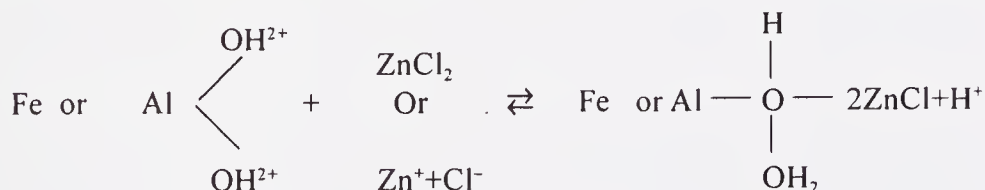
Adsorption Reactions of Zinc

Adsorption by oxide minerals: Clay minerals, sesquioxides, carbonates and soil organic matter are all recognized as being able to adsorb Zn^{2+} . The exact mechanisms of Zn^{2+} adsorption on oxide surfaces are not clear but several have been proposed. (a) A bridging ligand between two neutral sites. An octation bridge and ring structure is postulated. Such adsorption is considered a growth or an extension of the surface resulting in specific or irreversible retention of Zn^{2+} . In addition to the bridging between two neutral sites shown here, it has been suggested that Zn^{2+} could be adsorbed to the two positive sites or to a positive and neutral site.



(b) A second mechanism functioning at lower pH and resulting in nonspecific absorption of Zn^{2+} is proposed in the following adsorption reaction:-

In this process only one H^+ is released for each Zn^{2+} and the retained Zn^{2+} being less firmly held, can be replaced by other cations, such as Ca^{2+} , Mg^{2+} and Ba^{2+} .



Adsorption by Clay Minerals

Fixation of Zn^{2+} by clay minerals such as bentonite, illite and kaolinite has been reported by several investigations. The presence of iron and aluminum oxides influences this adsorption. Removal of iron oxides increases the capacity of clays to adsorb Zn^{2+} more frequently than it decreases (their retentiveness) it. Zn adsorption capacity is usually directly related to the cation exchange capacity of clays and hydrous oxides.

Adsorption by carbonate minerals

Zinc adsorption by carbonates or precipitation of $\text{Zn}(\text{OH})_2$ or ZnCO_3 is partly responsible for the unavailability of Zn^{2+} in calcareous soils. Detailed analysis of Zn^{2+} adsorption studies revealed that CaCO_3 content was the principal factor contributing to the Zn^{2+} adsorption maximum. Although ZnCO_3 was precipitated at higher Zn^{2+} concentrations, zinc availability to plants will not be seriously impaired because the solubility of this compound is too high for it to persist in soils. Zinc is most strongly absorbed by magnesite (MgCO_3) followed by dolomite and calcite (CaCO_3). Zinc is adsorbed into the crystal lattice surfaces at sites in the lattice normally occupied by magnesium atoms in the magnesite and dolomite.

Complexation by Soil Organic Matter

It is well known that zinc forms stable complexes with soil organic matter components. The humic acid and fulvic acid fractions are prominent in zinc adsorption. Three classes of reactions of organic matter with micronutrients such as zinc have been distinguished.

- Immobilization by high molecular weight organic substances such as lignin.
- Solubilization and immobilization by short chain organic acids and bases
- Complexation by initially soluble organic substances which then form insoluble salts.

Thus the action of organic matter on zinc can be expected to be variable depending on the characteristics and amount of organic materials involved. When immobilization and complexation reactions of organic matter prevail, availability of soil zinc will be adversely affected. This occurs in deficient peats and humic gley soils. On the other hand, formation of soluble chelated compounds of zinc will enhance availability by shielding the retained zinc from fixation reactions. Increased solubilisation and extractability of zinc may not always be reflected in enhanced zinc uptake by plants.

Organic matter in soil may form organic complexes with Zn and thus may avoid its transformation to other forms. Organic matter application causes considerable decrease in water-soluble and exchangeable Zn. This may be attributed to the complexation of Zn by other ligands and microbial immobilization of Zn.

Interactions with other Nutrients

Metal cations including Cu^{2+} , Fe^{2+} and Mn^{2+} inhibit plant uptake of Zn^{2+} possibly because of competition for the same carrier site.

Phosphorus

High phosphorus availability induces zinc deficiency. This interaction occurs

when plants are grown on soil without sufficient zinc.

It seems that when plants are deficient in zinc their ability to regulate phosphorus accumulation is either lost or severely impaired. As a result, phosphorus is absorbed in such excess that it becomes toxic. The toxicity symptom of phosphorus resembles zinc deficiency. If zinc supplies in soil are adequate, this regulates phosphorus levels. It is generally believed that formation of $\text{Zn}_3(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$ are responsible for phosphorus induced deficiency. It is not correct. In fact, solubility of this compound is sufficiently high to readily provide zinc to plants.

ZnSO_4 is highly mobile in soil and contributes significantly to total zinc in solution. Solubility and mobility of Zn^{2+} in soils are believed to be increased by the presence of SO_4^{2-} and subsequent formation of ZnSO_4 .

SO_4^{2-} supplied as gypsum decreases molybdenum uptake, which increases concentrations of zinc as well as Fe and Mn. The slight lowering of pH that occurs when gypsum is used may contribute to higher availability of the Fe, Mn and Sulfur. Gypsum application decreases pH of the flooded rice soils and increases the yield and zinc uptake of rice.

Nitrogen

Liberal application of nitrogen fertilizer can stimulate plant growth and increases Zn requirement beyond the available supply. The amount and properties of nitrogen source and its placement in relation to the zinc fertilizer has a notable effect on zinc availability. Nitrogen fertilizers that are acid forming will increase the uptake of both native and supplemental zinc. On the other hand, fertilizers with a neutral or basic effect are known to depress zinc uptake. The effect can be ascribed to changes in pH.

Flooding

When soils are submerged the concentration of most nutrient elements in the soil increases, but this is not true for zinc. The lowering of pH that occurs when calcareous soils are submerged decreases zinc solubility. This could also be due to formation of less soluble minerals such as franklinite (ZnFe_2O_4) or sphalerite (ZnS).

Phogat *et al.* (1994) found a significant decrease in water-soluble + exchangeable Zn under continuous than under alternate submergence of soil. This decrease may be due to the formation of insoluble Zn or precipitation of Zn with CaCO_3 and hydrous oxides of Fe and Mn in soil.

Climatic Conditions

Zinc deficiencies are generally most pronounced during cool, wet spring seasons and often disappear with the coming of warmer weather. Increase in soil temperature has been shown to increase availability of Zn to crops. The growth and zinc uptake responses to zinc fertilizer have been shown to be greater at low temperature than at high temperature. This suggests that native soil zinc becomes more available in warmer soil and satisfies crop requirements.

Plant Factors

Species and varieties differ in their susceptibility to zinc deficiency. Maize and

beans are very susceptible to low zinc. Fruit trees, citrus and peach are also sensitive.

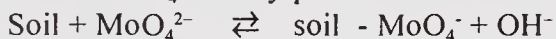
Different responses between two inbred for zinc appeared to be caused by differences in translocation requirements and utilization of zinc and imbalance accumulation of mineral elements that interact with zinc. Several differences among plant roots to exploit the soil for zinc is also responsible for varying responses by different species.

Molybdenum

Molybdenum occurs in the earth's crust and in soils in small quantities. The main forms of molybdenum in soil include: a) in non exchangeable positions in the crystal lattice of primary and secondary minerals, (b) as an exchangeable anion (c) bound to iron and aluminium oxides (d) as water soluble molybdenum in the soil solution and (e) as organically bound molybdenum. The major solution species of molybdenum in decreasing order of importance are $\text{MoO}_4^{2-} > \text{HMoO}_4^- > \text{H}_2\text{MoO}_4^-$. Above pH4.2, MoO_4^{2-} sp. is dominant. Concentration of MoO_4^{2-} and HMoO_4^- increases with increasing soil pH.

Soil pH and liming

Plant availability of molybdenum unlike that of other micronutrients, increases with increasing soil pH. Following relationship shows that there is a ten-fold increase in MoO_4 activity per unit increase in soil pH.



Thus changes in large magnitude (>100-fold increase) are expected when mineral wulfenite (PbMoO_4) is present in soil. (b) Liming to correct soil acidity will thus improve the Mo nutrition of plants. In most instances this practice is enough to correct Mo deficiency. (c) Studies have established that Mo uptake by plants is increased by the application of alkaline materials such as limestone and basic slag but is decreased by acid fertilizers such as $(\text{NH}_4)_2\text{SO}_4$ or nitrate.

Reaction with Fe and Al

Molybdenum is adsorbed strongly by iron and aluminum oxides. A portion of the adsorbed molybdenum becomes available to the plant while the remainder is in equilibrium with the soil solution molybdenum: As plant roots remove molybdenum from solution more molybdenum is desorbed in to the solution by simple mass action. (b) Because of adsorption reactions, soils that are high in iron, especially non-crystalline iron on clay surfaces, tend to be low in available molybdenum.

Interrelationship with other nutrients

Phosphorus enhances absorption and translocation of molybdenum by plants. This may be attributed to (a) The release of adsorbed MoO_4 , thus making it more available to plants. (b) Plant biochemical processes and stimulation of molybdenum release from root cells into the translocation system. (c) In contrast to phosphorus, high levels of SO_4^{2-} in the rooting media depress molybdenum uptake by plants. The restricting effect of sulphur application on molybdenum content is evident. Thus application of sulphur containing fertilizers may induce a molybdenum deficiency in plants in case soils contain a marginal molybdenum. (d) Both Cu and Mn act antagonistically on Mo uptake and if present in excess,

they may induce Mo deficiency. Magnesium has been reported to have an opposite effect and encourages molybdenum absorption by plants. e) The nitrate form of nitrogen encourages molybdenum uptake by plants while ammoniacal sources act oppositely.

Environmental Factors

Molybdenum deficiency has been found to be more severe under dry soil conditions in which the soil is unable to supply sufficient molybdenum for the growing plants. Transport of molybdenum from soil to root surfaces by either mass flow or diffusion would be impaired by low soil moisture content.

Plant factors

The differential susceptibility of cauliflower varieties to molybdenum deficiency is unrelated to requirement for the nutrient, but rather their ability to extract soil molybdenum. Crops that are very sensitive to insufficient molybdenum are the legumes, citrus, beet, cotton, lettuce, spinach and tomatoes. Small grains tend to be more tolerant to low levels of available molybdenum in soil.

Chlorine

Chloride uptake and accumulation in plants is depressed by high concentration of NO_3^- and SO_4^{2-} . A mutual antagonism between Cl^- and NO_3^- has been observed for a number of plants including potato, tomato, sugarbeet. Lowering of NO_3^- uptake by increasing levels of Cl^- has been observed in barley, corn and wheat. This strong negative interaction between Cl^- and NO_3^- has been attributed to competition for carrier sites at root surfaces. Water soluble chlorine levels of <2 mg/kg are considered low.

SOURCE AND NEED FOR MICRONUTRIENT BALANCE

Micronutrients are needed in small quantities but at the same time the lack of these nutrients reduces crop yield drastically. The deficiencies may not be noticed until they have become so widespread that reduction in crop yield is significant. This necessitates the importance of source and balance of micronutrients for crop production.

Causes of Deficiency of Micronutrients

The deficiencies of micronutrients has been on increase because of several factors. The important among them are:

High yielding varieties: Higher yields require more plant nutrients and can deplete the supply of available nutrients in the soil. Succeeding crops may therefore suffer from micronutrient deficiencies.

Pure fertilizers devoid of micronutrients as impurities: Newer high analysis fertilizers contain fewer impurities and do not carry the micronutrient unless added specially.

Reduced use of organic materials: Manure contains some of every essential element and helps to prevent micronutrient deficiencies.

High doses of NPK fertilizers: It leads to imbalance of nutrients.

Critical Level Concept of Micronutrients

The critical level may be defined as the level, which demarcates the soil or plant from deficiency to sufficiency status. Once the critical levels of micronutrient concentrations are fixed in the soils and plants, whether the soil or plant is deficient in respect of a particular micronutrient can be determined in the laboratory. The critical limits are dependent on soil characteristics, age of the plant, plant part sampled for analysis, type of extractant, shaking time etc. The critical limits are not absolute finite values and they may vary. The critical limits may be determined by Cate and Nelson’s graphical procedure or by statistical examination.

Critical Level of Micronutrients in Soils

Critical levels presently used to categorize soils for micronutrient deficiency or sufficiency :

Micronutrient	Critical level (mg/kg)	Extractant
Zinc (Zn)	1.2	DTPA
Copper (Cu)	1.2	DTPA
Iron (Fe)	3.7 Non calcareous soils	DTPA
	6.3 Calcareous soils	DTPA
Manganese (Mn)	2.0	DTPA
Boron (B)	0.1	Hot water soluble
Molybdenum (Mo)	0.05	Ammonium oxalate

Critical Level of Micronutrients in Plants

When a soil is deficient in a particular micronutrient it is also reflected in the tissue concentration of plant parts. Plant micronutrient concentrations are indication of (i) The available micronutrients status of soils and (ii) Soil environment. Thus micronutrient deficiencies can be diagnosed. The standardization of procedure is, however, important. The critical level of micronutrient in plants are determined following procedure as in case of soils. Tissue concentration is the result of several interacting factors such as soils, plants, environment, age of the plant etc. It is possible to suggest the deficiency or sufficiency status in plants. Sampling procedure for some crops have been given in Table 20.7.

The micronutrients are needed only in small amounts and any excess is known to produce toxic effects. Also, one should be cautious about the interactions with other nutrients, because the deficiency of one nutrient may result in the excess accumulation of other nutrients in plants. If deficiency is identified, there is response of crops to the application of micronutrients. Micronutrient fertilizers are used to overcome the deficiency and to obtain higher yields.

Precautions in Use of Micronutrient Fertilizers

While applying micronutrient fertilizers, following points should be

considered.

- Care must be taken in the application of micronutrient fertilizers. Some of the micronutrient elements may be toxic to plants.
- Micronutrients should be uniformly distributed over the area. Uneven distribution may cause toxic concentration at few places while others may be left deficient. Mixed fertilization is good solution to avoid this problem.
- The suitable source of micronutrient element should be used. Soil characteristics and fixation of nutrients may be considered. For example, boron compounds are soluble in water and make the water toxic to plant growth. Boron toxicity is more dependent on high boron contents in irrigation water than in soil.
- Useful method of application should be adopted. For example, foliar sprays may be more beneficial while applying micronutrient to a standing crop.

Management of Micronutrient Fertilizers

The following points must be considered for management of micronutrients in soil and plant system.

Boron in Soil

Less than 5% of the total boron is generally available to plants. Soil minerals containing boron are practically insoluble in water. Thus, concentration of boron in soil solution is likely to be very low.

- Extraction with hot water is the most reliable evaluation of soil boron availability. In arid regions, toxic concentration of boron may occur because

Table 20.7. Sampling procedures for some crops

Crop	Stage of growth	Plant part to sample	Number of plant to sample
Maize	Seedling stage or	All the above ground portions	20–30
	prior to tasselling	The entire leaf fully developed below the whorl	15–35
	Groundnut	Prior to or at bloom stage Mature leaves from both the main stem and either cotyledon or lateral branch	40–50
Cotton	Prior to or at first bloom or when first squares appear	Youngest fully matured leaves on main stem	30–40
Cabbage and other head crops	Prior to heading	First mature leaf from centre of whorl	10–20
Carrots, onions and other root crops	Prior to root or bulb enlargement	Centre mature leaves	20–30
Lemon, lime	Mild season	Mature leaves from last flush of growth or new fruiting terminals	20–30

of irrigation water containing high amount of boron.

- Generally in the soils of arid regions, particularly in the saline alkali soils, its toxicity and in the acid and highly leached soils of humid regions, its deficiency is well known.

Boron in Plant

Normal plant leaves contain 25 to 100 mg kg⁻¹ boron. Alfalfa is a good indicator crop for boron. The symptoms are evident on young leaves because boron is relatively immobile in plants. It has been found that.

- Boron deficiencies retard uptake of calcium. With increase in calcium supply, the severity of the symptoms of boron toxicity becomes less.
- High potassium uptake caused higher boron uptake. The ratio of Ca/B to the plant is influenced by the supply of potassium, increase in K⁺ in the nutrient solution bringing about a lowering of Ca/ B ratio. Ca has no significant influence on the K/B ratio.

Copper in Soil

Most of the copper in soils is very insoluble and can only be extracted by strong chemical treatments, which dissolve various mineral structure or solublize organic matter.

- Most copper minerals are of very low solubility.
- Copper is strongly adsorbed to clays, aluminium and iron hydrous oxides and manganese oxides. Cu forms stronger Cu- organic bonds than other metal ions.
- Copper deficiency is common in (a) sandy soil (b) organic soils (c) calcareous soils

Copper in Plant

Copper content of most plants varies between 5 to 50mg kg⁻¹. Copper is relatively immobile in plants and symptoms of deficiency occur on newer growths.

- Copper uptake seems to be inversely related to iron uptake. Too little copper causes iron to accumulate in plants.
- Excess of copper causes chlorotic symptoms similar to those of iron deficiency.
- There is competition of copper with other metals for uptake by the plants.

Iron in Soil

Application of ferrous to calcareous soils is not effective. The problem being low availability resulting from the high pH in such soils. The added iron react to form ferrous hydroxide or other insoluble compounds.

- Iron deficiencies may result if the soil minerals do not gradually release ferrous iron. This is necessary as ferrous iron is being oxidized to ferric iron in naturally occurring processes.
- Iron deficiencies can also occur from an excess of manganese or copper. Manganese and copper can serve as oxidizing agents and convert ferrous iron to insoluble ferric form.

Iron in Plant

Iron has a tendency to become unavailable within the plants.

- Deficiency of iron in plants affects the younger leaves more than older leaves because iron is relatively immobile inside the plant. The veins remain green while the areas between veins turn yellow from chlorosis.
- Larger root systems and increased solubility of iron at higher temperatures help plants obtain more iron in the summer.

Manganese in Soil

Different forms of manganese (water soluble, exchangeable and reducible) exist in equilibrium in soils.

- Acid sandy soils are low in manganese because leaching has lost most of the supply. Manganese toxicity occurs in acid soils in case such soils have not been leached.
- Muck soils are deficient in manganese because the organic materials release and lose cations more easily than anions.
- Calcareous and overlimed soils, because of low solubility are low in manganese content. (even though, total manganese is sufficient in such soils). Increasing the Fe^{++} and Zn^{++} supplies can help to reduce Mn toxicity, because these ions reduce plant uptake of Mn^{++} .
- Lowering pH by addition of sulfur compounds can cause manganese toxicity. Liming to raise soil pH is effective for overcoming the toxicity.

Manganese in plant

Manganese deficiency can be diagnosed by visual symptoms mostly in leaves. Plant or tissue analysis and soil analysis helps diagnose hidden hunger and deficiency in soil.

- The usual range of manganese concentration in plants is from 20 to 400 mg kg^{-1} . Manganese is immobile in plants and deficiency symptoms will appear on young leaves in the plant first.
- The similarity between manganese and iron causes a form of competition between the two elements. Symptoms of iron toxicity correspond to symptoms of manganese deficiency, and symptoms of manganese toxicity correspond to those of iron deficiency.

Zinc in soil

Following soil conditions are most often associated with zinc deficiencies. (a) Acid sandy soils low in total zinc; (b) neutral or basic soils; especially calcareous soils; (c) soils with a high content of fine clay and silt; (d) soils high in available phosphorus; (e) some organic soils and sub-soils exposed by land levelling operations or by wind and water erosion.

- The solubility of zinc compounds in water is low.
- The zinc ion (Zn^{++}) is strongly absorbed on the cation exchange sites of silicate clays.

Zinc in Plant

The plant availability of Zn^{2+} is conditioned by a number of soil and

environmental factors. pH, adsorption on surfaces of clay, organic matter, carbonates and oxide minerals, complexation by organic matter, interaction with other nutrients and climatic conditions.

- Increased soil compaction and wetter soils reduced zinc uptake. However, in rice plants growing on flooded soil zinc uptake is significantly higher.
- Low soil temperature reduces zinc uptake.

Molybdenum in Soil

Molybdenum occurs in the earth's crust and in soils in extremely small quantities. In soil, it ranges from 0.2 – 5.0 mg kg⁻¹ with an average of 2.0 mg kg⁻¹.

- Phosphorus minerals usually contain some molybdenum as impurities. This is also true for phosphorus fertilizers.
- Most of the molybdenum is locked up in organic and mineral structures. It may be adsorbed on positively charged exchange sites.
- The available form is (MoO₄⁻) molybdenum ion. The solubility of MoO₄⁻ increases as the pH rises. Thus molybdenum deficiency is more likely in acid soils.

Molybdenum in Plant

The low concentration of molybdenum in soil solution is reflected in its low concentration (less than 1.0 mg kg⁻¹) in plant.

- Molybdenum requirement of plants is very small as compared to other micronutrients.
- Molybdenum deficiency can cause a nitrogen deficiency in the plant, because molybdenum is essential in symbiotic nitrogen fixation.

Micronutrient Mixtures

Micronutrients can be best utilized by supplying them as mixture fertilizers. It is based on following facts:

- The function of one element cannot be replaced in the plant by another element.
- As the demand for increasing production is pressing, no single element can be made to be the limiting factor.
- The law of limiting factor says that if any of the element falls short then the yields get restricted directly in proportion to the element that falls short.
- The high yielding varieties do not give expected yields because nutritional support in balanced form is lacking.
- Micronutrient mixture fertilizers help in better utilization of NPK fertilizers.
- NPK fertilizer do not give the expected percentage of returns as they were giving earlier because secondary and essential micro-nutrients are depleted and not being replaced along with NPK.
- There is no fear of toxicity in the use of micronutrient mixture fertilizers.
- Micronutrients fertilizer mixture adds to balanced plant nutrition programme, Other package practices may not give expected yields if nutritional balance of crops is not achieved.

Use of Organic Manure as a Source of Micronutrients

Mineral fertilizers as well as organic manure are essential to maintain sustained

Table 20.8. Composition of the organic materials and crop residues (in mg kg⁻¹) (Expressed on air drybasis).

Organics	Zn	Fe	Mn	Cu
Cattle manure	2.5	1260	75	2.4
Poultry manure	90.0	1380	210	7.1
Green manure	25.0	105	39	6.7
Wheat straw	26.0	48	25	5.6
Coir pith based poultry liter	160.0	971	167	27.0
Coir pith (raw)	7.5	0.07	1.25	3.1
Coir pith (composted)	1.06	0.09	20.10	6.2
Farmyard manure	126.0	3000	625.0	49.0

Singh *et al.* (1992)

productivity. Organic manure improve physical condition of the soil and maintain a continuous supply of micro-nutrients due to their chelating property. Organic manure contains some quantities of micro-nutrients (Table 20.8).

Phosphorus Micronutrient Interaction in Soil

Excessive P fertilization reduce the availability of micronutrients. Such an association of reduced micro-nutrient concentration with high P has been termed as 'P induced micronutrient deficiency'.

ZnxP

- Available P is decreased due to excess of zinc by formation of zinc phosphate.
- Mechanism involving P-Zn interaction which induces zinc deficiency are:
 - Dilution of Zn in plant tissues by promoting plant growth due to P fertilizers.
 - Inhibition of Zn absorption by cations added with P fertilizers.
 - Formation of oxides and hydroxides of Fe and Al in the soil resulting in the decreased absorption of Zn by plant roots.
- An excessive concentration of P interferes with the metabolic function of Zn at certain sites in the cells.

FexP

Fe and P have antagonistic effect. This is attributed to the precipitation of Fe_3PO_4 on the root surfaces. For maximizing crop yields on soils low in both P and Fe, application of P should be accompanied with addition of Fe. The effect of P on Fe absorption is due to the competition between P and organic ligands within the plant, which function to maintain Fe in soluble mobile form.

MnxP

Beneficial effects of applied P on the availability of Mn have been established. Due to the accumulation, the concentration of Mn in roots increased.

CuxP

The interaction between Cu and P is antagonistic. The excess of P and Cu in

the leaves interferes with the metabolic translocation of Fe and make Fe inactive for chlorophyll synthesis.

BxP

It is usually synergistic. Added B increases the permeability of plasmalemma at the root surface allowing more absorption of P by the roots.

Mo x P

Synergistic effect of Mo with P is due to formation of phosphomolybdate, which can be readily absorbed by the plants.

MICRONUTRIENT FERTILIZERS AND SOIL MANAGEMENT

The rates of micronutrient fertilizers, which are needed by different crops, method of application of micronutrients and time of application, are all varying factors. The variations are found to occur due to heterogeneity of the soils, difference in climatic conditions and even management practices.

Methods of Application of Micronutrients

Micronutrients may be applied through various ways:

Soil application, broadcast or banded: Soil application of micronutrient fertilizers have a long residual effect. Nutrient interaction may take place in soil application of micronutrients.

Broadcast: In this method, micronutrient is spread over the entire soil surface by hands or some mechanical spreader. The micronutrients may be mixed with small amount of soil for their uniform distribution. Usually it is practiced before sowing. Application of micronutrients in standing crop (top dressing) is not common.

Band Placement: In this method micronutrients are applied in bands. The micronutrients are applied keeping the position of seed in view. The micronutrients are placed on the sides of seeds about 7.5 cm below the seed layer so that injury to germinating seedlings due to contact with micronutrient could be avoided. The micronutrient becomes readily available to plants. The nutrient is effectively utilized as this assures adequate supply of nutrient to plants.

Foliar application as sprays: Foliar sprays are effective to correct micronutrient deficiency in growing crops. Foliar sprays may be repeated (in case of deficiency) as they do not have residual effect. For example, several sprays are needed to correct chlorosis. Boron is immobile, thus a number of sprays are necessary to meet out boron deficiency. Sprays should be made during morning hours.

Dipping roots of transplanted crop in solutions or suspensions: Root dipping has no residual effect and needs to be repeated. It is common for application of zinc. Roots are dipped in 2% solution of zinc oxide. Zinc oxide sticking to the roots may be washed and effectiveness of treatment may be less.

Dusting seeds with powder or soaking them in solution: It is practiced for micronutrients which are needed to be applied in very small amounts for their

Table 20.9. Method of micronutrient application and their concentration

Micro-nutrient	Time of Application	Salt and their concentration	Caution
Zinc	Foliarspray: 2–4 times at biweekly intervals. Dipping seeding roots of rice in 2–4% zinc oxide suspension. Sett dipping in 2% zinc oxide for sugarcane	0.5% ZnSO_4 500 litres sprays solution/ha	The leaves should be thoroughly wet during spray.
Iron	At the interval of 14 days	Organic chelates 1–3% ferrous ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) 400-500 liters of solution /ha The spray may be repeated in 7 to 10 days if needed.	Neutralization of iron with lime is necessary. (half the amount of iron)
Mn	2-3 sprays at 14 days interval	MnSO_4 0.5 to 1%	It is most effective for correcting Mn deficiency.
Cu	At biweekly intervals	0.5% CuSO_4 through $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	Can be corrected through foliar application
Mo	Usually given as seed treatment for uniform distribution of small amount of molybdenum @ 50-100 g/ha	0.1 to 0.3% Mo. Salt.	For foliar spray Mo salt should be soluble in water. For seed treatment in liquid form.
B		1–5 kg/ha. Boron is preferred	

Note: Soil application of micronutrients have not been included

uniform distribution.

Different method of micronutrient application, their salt concentration and precautions have been given in Table 20.9. Sources and elemental composition of common micronutrient fertilizers are given in Table 20.10.

Application Methods and Rates of Micronutrient Fertilizers

Boron: Borax and sodium tetraborate are commonly used boron fertilizers. Boric acid is also used sometimes. Borax is soluble in water and therefore easily available to plants. Soil application may produce residual effect for the subsequent crop.

The most common methods of boron application are broadcast, banded or applied as a foliar spray or dust. In the first two method, boron fertilizer source is mixed with NPKS products and applied to soil. Finely divided boron salts can be coated on dry fertilizer materials.

Foliar application of boron is practiced for perennial tree fruit crop. Boron may also be included in spray of zinc chelate, magnesium, manganese and urea. Foliar application of boron with insecticide are also used in cotton, Three to four

Table 20.10. Sources and elemental composition of common micronutrient fertilizers

Source	Formulae	Per cent micronutrient element
<i>Boron</i>		
Borax	$\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$	11
Sodium pentaborate	$\text{Na}_2\text{B}_{10}\text{O}_{16} \cdot 10\text{H}_2\text{O}$	18
Solubor	$\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O} + \text{Na}_2\text{B}_{10}\text{O}_{16} \cdot 10\text{H}_2\text{O}$	20
Boric acid	H_3BO_3	17
Boron frits	—	2–6
Sodium tetraborate: Borate 46	$\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$	14
Borate 65	$\text{Na}_2\text{B}_4\text{O}_7$	20
<i>Copper</i>		
Cupric sulphate Pentahydrate	$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	25
Cupric sulphate monohydrate	$\text{CuSO}_4 \cdot \text{H}_2\text{O}$	35
Basic cupric sulphate	$\text{CuSO}_4 \cdot 3\text{Cu}(\text{OH})_2$	13–53
Malachite	$\text{CuSO}_3 \cdot \text{Cu}(\text{OH})_2$	57
Azurite	$2\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$	55
Cuprous oxide	Cu_2O	89
Cupric oxide	CuO	75
Cupric acetate	$\text{Cu}(\text{C}_2\text{H}_3\text{O}_2)_2 \cdot 2\text{H}_2\text{O}$	32
Cupric oxalate	$\text{CuC}_2\text{O}_4 \cdot \text{H}_2\text{O}$	40
Cupric ammonium phosphate	$\text{Cu}(\text{NH}_4)\text{PO}_4 \cdot \text{H}_2\text{O}$	32
Copper chelates	Na_2CuEDTA	13
Copper polyflavonoid	—	5–6–7
<i>Iron</i>		
Ferrous sulphate	$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	19
Ferric sulphate	$\text{Fe}_2(\text{SO}_4)_3 \cdot 4\text{H}_2\text{O}$	23
Ferrous oxide	FeO	77
Ferric oxide	Fe_2O_3	69
Ferrous ammonium phosphate	$\text{Fe}(\text{NH}_4)\text{PO}_4 \cdot \text{H}_2\text{O}$	69
Ferrous ammonium sulphate	$(\text{NH}_4)_2\text{SO}_4 \cdot \text{FeSO}_4 \cdot 6\text{H}_2\text{O}_{20}$	
Iron frits	Varies	Varies
Iron ammonium phosphate	$\text{Fe}(\text{NH}_4)\text{HP}_2\text{O}_7$	22
Iron chelates	NaFeHEDTA	5–14
	NaFeEDTA	5–9
	NaFeEDDHA	6
	NaFeDTPA	10
Iron polyflavanoids	—	9–10
<i>Manganese</i>		
Manganese sulphate	$\text{MnSO}_4 \cdot 3\text{H}_2\text{O}$	26–28
Manganese oxide	MnO	41–68
Manganese chelate	MnEDTA	12
Manganese carbonate	MnCO_3	31
Manganese chloride	MnCl_{12}	17
Manganese oxide	MnO_2	63

Table Continued

Source	Formulae	Per cent micronutrient element
Manganes frits	—	10-25
<i>Molybdenum</i>		
Sodium molybdate	$\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$	39
Ammonium molybdate	$(\text{NH}_4)_6\text{Mo}_6\text{O}_{24} \cdot 4\text{H}_2\text{O}$	54
Molybdenum trioxide	MoO_3	66
<i>Zinc</i>		
Zinc sulphate monohydrate	$\text{ZnSO}_4 \cdot \text{H}_2\text{O}$	35
Zinc sulphate heptahydrate	$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$	23
Basic zinc sulphate	$\text{ZnSO}_4 \cdot 4\text{Zn}(\text{OH})_2$	55
Zinc oxide	ZnO	78
Zinc carbonate	ZnCO_3	52
Zinc sulphide	ZnS	67
Zinc frits	(Silicates)	Varies
Zinc phosphate	$\text{Zn}_3(\text{PO}_4)_2$	51
Zinc chelates	Na_2ZnEDTA	14
	NaZnNTA	13
	NaZnHEDTA	9
Zinc polyflavanoids	—	10

sprays may be given depending upon the severity of the symptoms. Boric acid or solubor at a concentration of 0.2 to 0.5% may be suitable. Wetting of 400 litres of spray solution mixed with 0.1% urea alongwith any wetting agent in the new foliage facilitate easy absorption.

Rate of boron fertilization depend on plant species, soil cultural practices, rainfall, liming and soil organic matter.

Copper: Copper is more effective through band placement. When broadcast copper fertilizers should be mixed into the soil. $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ makes bordeaux mixture effective as a copper fertilizer as well as a fungicide. Cu frits are suitable for soil application. Chelates of Cu and other micro-nutrients are used. Accessibility of soil applied Cu to plant roots is important and utilization is enhanced by reducing particle size and increasing the number of granules per unit soil volume. Effectiveness is also increased by thoroughly mixing copper fertilizers in to the root zone or by banding them in the seed row. Higher rates of copper are required to compensate for the low mobility of exchangeable Cu^{++} . Copper dusts or solutions can be used for seed treatment.

Iron: Iron should be applied as their chelates through band placement. When applied as inorganic fertilizers, Fe is converted to their unavailable forms. In general, soil applications of ionizable ferrous salts such as FeSO_4 have not been satisfactory because of their rapid oxidation to much less soluble ferric forms. Mainly foliar sprays do correction of iron deficiency. One dressing of a 2–3% ferrous sulphate solution (1.5–3.0 kg/hactare sufficient to alleviate mild chlorosis.)

Injection of iron salts directly into trunks and limbs of fruit trees is effective in

controlling iron chlorosis. Synthetic chelates and organic complexes are also used.

Manganese: Manganese may be applied alongwith acid forming fertilizers (availability of manganese is more under acid conditions.) either through broadcast or band placement.

$\text{MnSO}_4 \cdot 4\text{H}_2\text{O}$ (soil, foliar), chelated, organically complexed or frits forms are used. Band application of Mn in combination with NPK is a superior way of providing manganese as compared to broadcast. Oxidation to less available forms of Mn is apparently delayed in bands.

Broadcast application of Mn chelates and organic complexes is not advised because soil calcium or iron can replace the Mn in these fertilizers and the freed manganese is usually converted to unavailable forms. Application of manganese to alkaline soils is generally not successful because of the low solubility of manganese in alkaline conditions. Chelate form is preferred on alkaline soils. Manure usually contains enough manganese to prevent manganese deficiency when it is applied regularly.

Zinc: Zinc should be mixed in soil well before sowing. Zinc may be broadcast or banded. In band placement, zinc fertilizers are placed beside and below the seed. ZnSO_4 may be applied @ 2–20 kg of Zn/ha. Zinc oxide, zinc chelated and other forms are commonly used. Sometimes a more slowly available form is preferable because of its long lasting effect. For example, zinc oxide fused with sulfur supplied zinc over a period of years.

Because the mobility of zinc can be very limited in soils, zinc should be mixed thoroughly and deep in to the soil. Soils that are basic or calcareous, spatial distribution of zinc fertilizer granules plays important role in supplying sufficient zinc to plant roots.

Foliar application is used primarily for tree crops. Sprays containing up to 5 kg of ZnSO_4 /litre of water are applied @ 10–15 kg/ha of zinc to dormant orchards.

The efficiency of banded zinc application can be improved by the presence of nitrogen fertilizers particularly those that acidify the soil. Plant residues and manure returned to the soil contain zinc. These will help to meet out zinc deficiencies in soil.

Molybdenum: Molybdenum can be applied through broadcast or band placement. Molybdenum has a long residual effect. Rates of molybdenum applications are very low, only 40 to 400 g/ha. Molybdenum may be applied to soil, sprayed on foliage or put on seed prior to planting. Molybdenum requirements are so small that the necessary amount can be supplied by treating it with the seed. Seed treatment involving soaking seed in a solution of sodium molybdate before seeding, is used because of the low application rates needed. A slurry or dust treatment of the seed is also effective. As little as 5–10g of Mo/ha as sodium molybdate or ammonium molybdate has produced satisfactory plant growth on molybdenum deficient soils. Molybdenum fertilizer alongwith lime is more effective to overcome a molybdenum deficiency. Foliar spray application with ammonium or sodium molybdate is also effective in correcting molybdenum deficiency.

Chlorine: Most of chloride fertilizers are NH_4Cl , CaCl_2 , MgCl_2 , KCl , NaCl etc. Rates of chloride will vary depending on a number of conditions, including

species, method of application and purpose of addition. The Cl^- anion is bound by most soils in the acid to neutral pH range and becomes negligible at $\text{pH} > 7$. Appreciable amounts of chloride can be absorbed, with increasing acidity, by kaolinite soils, which have significant pH – dependent positive charge. Non specifically adsorbed anions such as NO_3^- , Cl^- and SO_4^{2-} are readily exchangeable because they are held in solution some distance away from the mineral surface. The divalent SO_4^{2-} ion is adsorbed more strongly and completely than the monovalent Cl^- and NO_3^- ions. Chloride is often used as indicator of NO_3^- mobility because the former is not subject to biological and chemical transformations, and in most other aspects these ions behave similarly. Because of the great mobility of Cl^- in soil it can be rapidly recycled through soil systems. The principal effect of too much Cl^- is to increase the osmotic pressure of soil water and thereby lower the availability of water to plants.

Production of Micronutrient Fertilizers

Unlike NPK fertilizer industries, which are mainly with large industrial establishments, the micronutrient fertilizer industries are primarily developed and promoted by private sector (small and medium scale industries). Among the micronutrient fertilizers zinc sulphate is largely produced in states like Punjab, Haryana, Uttar Pradesh, Gujarat, Tamil Nadu and Maharashtra whereas most of the micronutrient fertilizers are largely produced in Maharashtra, Gujarat, Tamil Nadu and to some extent in Karnataka. For NPK fertilizers, the government has special policies with respect to import, production, season wise supply plan, allocation, price regulation, subsidy, transport, distribution etc. However, no such system exists (except subsidy to selected micronutrients in some states) for micronutrient fertilizers. (Micronutrient News, March 1994)

Micronutrient fertilizers and their use are fairly well recognized in the country. The Government of India brought the micro-nutrient fertilizers under the fertilizer control act cover on legal, regulatory and quality control aspects of fertilizers. Single micronutrient fertilizers used are the simple inorganic salts (like sulphates of zinc, iron, copper and manganese, borax, boric acid and ammonium molybdate) and EDTA chelates of zinc and iron.

Multinutrient fertilizer grades are micronutrient mixture formulations containing two or more micronutrients with or without secondary and major nutrients. While the single micronutrient fertilizers are notified by the Centre, the multi micronutrient fertilizer grades are decided by the States, based on the soil and crop requirements.

Soil and foliar application methods are manually followed. Root dipping and seed treatment methods are still not popular. Soil and plant tissue analysis is adopted as diagnostic method for micronutrient status.

Constraints in Use of Micronutrient Fertilizer

The limitation in micronutrient fertilizers involve technical, regulatory, production, distribution, marketing, in nature. The main constraints are:

- **Deficiency and demands:** Current methods of assessment of deficiency based on soil and leaf tissue analysis are successful only to a small extent. The limitations of critical limits and the need for higher requirement per unit area

per unit time for crops that are high yielding and grown in deficient areas should be recognized.

- Hidden and visible deficiency: The hidden deficiency is a situation containment of plants by imposing self-restriction on growth and yield. Visible deficiency is an aggravated situation limiting growth and productivity. Plant should be prevented from both, hidden and visible deficiency.
- Single and multi micronutrient deficiency: The results of soil and plant tissue are often presented on single nutrient basis. Deficiency of more than one micronutrient exists in many areas in the country.
- Synergism and antagonism: It is important to know the limits or range under which the synergism or antagonism of nutrients takes places.
- Uptake and transport: Nutrient uptake studies to generate information on mode of application, nutrient combinations, ability to support the crop demand during peak growth stages, are needed.
- Simple salts and chelates: Use of salts and chelates, their benefits and use under different soil situations should be understood.
- Awareness: The information should be passed on to the consumers for the benefit of food production.
- Role of physiologist biochemists: The contribution of physiologists and biochemists should be recognized in following fields:
 - Role in areas of biochemical means of deficiency at early stage of crop growth
 - Physiological support of synergism and antagonism
 - Nutrient uptake in relation to crop growth
 - Efficiency of different sources likes inorganic salts and chelates of different types.

References and Suggested Readings

- Agarwala, S.C. and Sharma, C.P. (1979). Recognizing micronutrient disorders of crop plants on the basis of visible symptoms and plant analysis. Botany Department, Lucknow University.
- Bhattacharya, B.K. (1992). Importance of micronutrient in crop production. *Proc. IDFEP HFC Workshop on Micronutrient*. Bhubaneswar.
- DeRemer, F.E. and Smith, R.L. (1964). *Agronomy Journal* **56** : 57.
- Hemantaranjan, A. (1996). *Advancements in Micronutrient Research*. Scientific Publishers, Jodhpur, India.
- Kanwar, J.S. and Randhawa, N.S. (1974). Micronutrient research in soils and plants in India (A review). Indian Council of Agricultural Research, New Delhi. *Technical Bulletin* (Agric.) No. 50.
- Katyal, J.C. and Pathak, A.N. (1983). Importance of secondary and micronutrient in multiple cropping systems. Indian experinecc. Paper 10 in *Fertiliser Use under Multiple Cropping Systems* FAO Fertilizer and Nutrition Bulletin **5**.
- Katyal, J.C. Zinc deficiency in Indian soils and crops. *Technologies for Better Crops* No. 43, ICAR.
- Lal, K.N. and Subba Rao, M.S. (1954). *Microelement Nutrition of Plants*. BHU, Varanasi.
- Mitchell, R.L. (1965) *The Chemistry of the Soil*, (Ed.). Bear F. E., Pub. Oxford and IBH Pub. Co., New Delhi.

Nambiar, K.N. (1994) *Fertilizer News* **39** : 41–45.

Nicholas, N.A. (1963). *Soil Conditions and Plant Growth*. Walter, E. Russel (1975). The English Language Book Society and Longman.

Phogat, V., Dahiya, D.J. and Singh, J.P. (1994). *Journal of Indian Society of Soil Science* **42**: 239–43.

Rattan, R.K. Sharma, N. and Dutta, S.P. (1999) *Fertilizer News* **44** : 35–50.

Sankaram, A. (1975). *Textbook of Agricultural Chemistry Soil Science*. Genesis-Survey Classification. The Bangalore Printing and Pub. Co. Ltd., Bangalore.

Singh et al (1992). *Micronutrient News*, Vol. X, No. 6, July 1996, Pune.

QUESTIONS

Q. 1. Fill in the blanks

- i) Plants grown in alkali soils, suffer from zinc deficiency due to high _____ and presence of _____ carbonate.
- ii) Iron, copper and _____ may enter into oxidation reduction reactions as these elements can change their valencies.
- iii) _____ is required for proper development and differentiation of tissues particularly vascular elements.
- iv) _____ is required for nitrogen fixation by organisms such as *Azotobacter* and *Clostridium*.
- v) _____ is a constituent part of the enzyme nitrate reductase and nitrogenase.
- vi) Most of the trace elements such as Zn, Mo, Co, and Cu occur in easily weathered constituents of _____ rocks.
- vii) _____ constitute 80 per cent of the total sedimentary rocks
- viii) Boron occurs as _____ at pH greater than 8.5.
- ix) The most prominent boron mineral in soils is _____.
- x) Extraction with hot water is the most reliable evaluation of soil _____ availability.
- xi) The occurrence of copper deficiencies following the use of acid forming fertilizers, may be due to the increased _____ levels in soil solution.
- xii) Iron has a tendency to become _____ within the plants.
- xiii) Solubility of iron reaches minimum between pH _____ to _____.
- xiv) The low availability of Mn^{+} in basic soils, high in organic matter is attributed to the formation of _____.
- xv) At higher pH, zinc forms insoluble compound such as _____ and _____ which can reduce available zinc in soils.
- xi) Most of the zinc in soils is located in _____ minerals such as augite, hornblende and biotite.
- xvii) Plants take up zinc as _____ ion.
- xviii) Plants absorb molybdenum as _____ ion.
- xix) Organic manure maintain a continuous supply of micro-nutrients due to their _____ property.

- xx) Synergistic effect of Mo with P is due to formation of _____ which can be readily absorbed by the plants.

Answers

(i) pH, sodium (ii) manganese (iii) Boron (iv) Molybdenum (v) Molybdenum (vi) igneous (vii) Shales (viii) $B(OH)_4$ (ix) Tourmaline (x) boron (xi) aluminium (xii) Immobile (xiii) 7.4 to 8.5 (xiv) unavailable chelated Mn compounds (xv) $Zn(OH)_2$ and $Zn CO_3$ (xvi) ferromagnesian minerals (xvii) Zn^{2+} (xviii) MoO_4^{2-} (xix) chelating (xx) phospho molybdate.

Q. 2. Choose the correct answer

- i) Foliar application/ soil application of micronutrient is more suitable to avoid elemental interaction
- ii) Zinc/ copper activates enzyme carbonic anhydrase and dehydrogenase
- iii) Copper / iron is present in cytochrome oxidase
- iv) Manganese/ zinc has a primary role in the tricarboxylic acid cycle
- v) Chlorophyll, the green pigment in leaves is a chelate of magnesium/ iron
- vi) Chelates/ inorganic salts are beneficial in terms of mobility and response
- vii) Soils formed from basic rocks/ acidic rocks are likely to have a high content of Co, Ni, Cr, Mn and Cu
- viii) Soils derived from argillaceous shales and slates/ sandstone tend to be rich in trace elements
- ix) The distribution of trace elements from soil parent materials enables one to anticipate the total content of trace element with more accuracy in young soil/ those soils that have undergone weathering
- x) Major part of cation exchange capacity of organic matter is due to the presence of COOH group/phenolic groups,
- xi) Most of the copper in soils is insoluble/ soluble
- xii) The accumulation of copper occurred in molybdenum/ iron deficient leaves
- xiii) Potato and sugarbeet are tolerant to low level of available iron/ zinc in soil
- xiv) Waterlogging lowers redox potential and increase/ decrease the amount of soluble Mn^{2+} in soils
- xv) Barley/ oats can survive under low levels of available manganese in soil
- xvi) Removal of iron oxides increased/ decreases the capacity of clays to adsorb Zn^{2+} more frequently than it decreases it
- xvii) Zinc is more strongly adsorbed by magnesite/ calcite
- xviii) Formation of soluble chelated compounds of zinc will increase/ decrease its availability
- xix) $Zn_3(PO_4)_2 \cdot 4H_2O$ is soluble/ insoluble
- xx) Nitrogen fertilizers that are acid forming will increase/ decrease the uptake of zinc
- xxi) Liming to correct soil acidity will improve Mo/Mn deficiency
- xxii) Small grain crops are tolerant to low levels of Mo/Cu in soil
- xxiii) Borax/ Boric acid is soluble in water and therefore easily available to plants

Answers

(i) Foliar application (ii) Zinc (iii) Copper (iv) Manganese (v) magnesium (vi)

Chelates (vii) basic rocks (viii) slates (ix) young soil (x) COOH group (xi) insoluble (xii) molybdenum (xiii) iron (xiv) increase (xv) Barley (xvi) Increases (xvii) magnesite (xviii) increase (xix) soluble (xx) increase (xxi) Mo (xxii) Mo (xxiii) Borax

Q. 3. Define the following

(i) Nutrient (ii) Chelates (iii) Multi nutrient fertilizer (iv) Chlorosis (v) Mottling (vi) Necrosis

Q. 4. Differentiate between

(i) Macronutrient and Micronutrient (ii) Primary and Secondary nutrient deficiencies (iii) Hidden hunger and Visible deficiency (iv) Inorganic salts and Chelate (v) Mn- efficient and Mn –inefficient oat plants (vi) Soil and Foliar application of micronutrients

Q. 5. Write short notes on

(i) Hidden hunger (ii) Role of iron in plants (iii) Role of chlorine in plants (iv) Iron imbalance in plants (v) Iron phosphorus relationships in plants (vi) Critical level concept (vii) Precautions in the use of micronutrient fertilizers (viii) Phosphorus – micronutrient interaction in soils

Q. 6. Comment on the following statements

- i) The content of a plant nutrient in plant parts does not give a true indication of the quantity effectively needed for physiological and biochemical processes
- ii) The use of micro-nutrient is complicated
- iii) Plants grown in alkali soils, suffer from severe deficiency of zinc
- iv) Goitre is common in Himalayan regions
- v) Boron and molybdenum cannot be chelated
- vi) The micronutrients from the standpoint of soil chemistry can be put in three group namely heavy metal cations, the divalent cations and as anions
- vii) Variations in the content of most trace elements in soils is far greater than variations in macro-nutrients
- viii) Plants take up larger quantities of boron from sandy soils than will from fine textured soil at equal concentration of water soluble boron
- ix) Organic matter content increases boron availability
- x) Boron is more available in surface soil as compared to sub surface soil
- xi) Ca/B ratio in leaf tissues has been used to assess the boron status of crops
- xii) Usually there exists a synergistic relationship between boron and phosphorus
- xiii) The mobility of copper in soil solution decreases with increasing pH
- xiv) Incorporation of crop residues may immobilise copper in soil solution
- xv) There are genotypic differences in the copper nutrition of plants
- xvi) Irrigation waters and soils high in bicarbonate may aggravate iron

- deficiencies
- xvii) Calcareous soils are deficient in iron
- xviii) Addition of organic matter to well drained soils produces favorable effects on the availability of iron
- xix) Plants receiving NO_3^- nitrogen and NH_4^+ nitrogen have varying effects on the availability of iron
- xx) Roots of iron efficient plants can alter their environment to improve the availability and uptake of iron
- xxi) Management practices that change soil pH will greatly influence Mn^{2+} availability and uptake
- xxii) Not all basic soils are deficient in zinc
- xxiii) Liming acid soils will reduce uptake of Zn^{2+}
- xxiv) Metal cations such as Cu^{2+} , Fe^{2+} and Mn^{2+} inhibit plant uptake of zinc
- xxv) Phosphorus fertilization of zinc deficient plants produces toxicity of phosphorus
- xxvi) The lowering of pH that occurs when calcareous soils are submerged decreases zinc solubility
- xxvii) The growth and zinc uptake responses to zinc fertilizer have been shown to be greater at low temperature than at high temperature
- xxviii) Plant species and varieties differ in their response to application of zinc
- xxix) Soils high in iron, tend to be low in available molybdenum
- xxx) Phosphorus enhance the absorption and translocation of molybdenum by plants
- xxxi) Molybdenum deficiency has been found to be more severe under dry soil conditions
- xxxii) Chloride is often used as an indicator of NO_3^- mobility
- xxxiii) The rate and extent of migration and accumulation of Cl^- in soils is dependent on water circulation
- xxxiv) There is a negative interaction between Cl^- and NO_3^-
- xxxv) It is possible to suggest the deficiencies status in plants
- xxxvi) Molybdenum deficiency can cause nitrogen deficiency in the plants
- xxxvii) Accessibility of soil applied Cu to plant roots is important
- xxxviii) Iron should be applied as their chelates through band placement
- xxxix) Band application of Mn fertilizers is better as compared to broadcast
- xl) Zinc should be mixed thoroughly and deeply into the soil
- xli) Molybdenum fertilizers alongwith lime is effective to overcome a molybdenum deficiency

Q. 7. Answer the following in brief

- i) What are the criteria of essentiality of a nutrient
- ii) What are the limitations of soil and plant analysis in the diagnosis of nutrient deficiencies
- iii) What is the significance of micro-nutrients in man and animal health
- iv) Enlist three natural cheating agents
- v) What qualities should a chelate possess
- vi) Explain the mechanism of nutrient absorption through chelates

- vii) What are the limitations in the use of chelates
- viii) Enlist the relative ease of displacement of following cations: Na, Ca, Co Li and Cu and anions molybdate and phosphate
- ix) Enlist factors influencing availability of micro-nutrients to plant growth
- x) What is the effect of liming on the availability of boron
- xi) Enlist common forms of copper in soil
- xii) Enlist common zinc containing minerals in soil
- xiii) What type of reactions with organic matter and micro-nutrients commonly occur in soil
- xiv) Enlist main forms of molybdenum in soil
- xv) Discuss the effect of soil pH and liming on the availability of molybdenum in soil and plant
- xvi) Enlist the causes of deficiencies of micronutrients in soil

Q. 8. Answer the following in detail

- i) Classify plant nutrients according to their biochemical behavior and physiological functions
- ii) Micronutrients can be best utilized by supplying them as their mixture fertilizers (micronutrient mixtures). Justify giving details
- iii) What are the constraints in the use of micronutrient fertilizer

Q. 9. Give diagrammatic view of the following

The mechanism of Zn^{2+} adsorption on surfaces of oxide minerals.



Soil Organisms

Soil organisms constitute only a small fraction of the total soil mass. Living organisms include both macro and micro-organisms. The macro-organisms have a significant effect on the physical properties of soil. The role of soil organisms can be summarized as follows:

- Certain microbial species reduce nitrogen in soil and this nitrogen is utilised by plants and micro-organisms. For example, *Rhizobium*, *Bradyrhizobium* (symbiotic N-fixing bacteria), *Azolla*, *Anabaena*, (symbiotic cyanobacteria), *Fankia*, (symbiotic actinomycetes), *Azotobacter*, *Clostridium*, *Azospirillum*, (non-symbiotic N-fixing bacteria) and *Nostoc*, *Anabaena*, (cyanobacteria).
- The debris of plants, animals and human beings are returned to the soil after completing their life span. Fresh group of plants and animals meet their food requirement from them. This cycle goes on and maintains soil- plant- animal ecosystem.
- Soil organisms play a key role in nutrient transformations. Organic forms are transformed into their respective inorganic forms and plants are able to absorb them for their growth. The inorganic elements are transformed back into organic form by soil organisms. Free living micro-organisms in soil, which do not directly come into contact with plants also, play an indirect role in the well being of plants.
- Microbial decomposition of organic matter is an essential step for release of the bound nutrients in organic residues into an available form to release the organically bound nutrients into an available form and synthesis of humic substances. All these products influence physical and chemical properties of soil and hence plant growth.
- The CO₂ content of soil air (0.3–1.0% by volume) is higher than that of the atmospheric air (0.03% by volume). This is due to the respiratory activity of soil organisms in which O₂ is consumed leading to lower O₂ content of soil atmosphere.
- Soil micro-organisms help in the formation and development of soil through

Table 21.1. Micro-organisms in a fertile soil (millions)

Bacteria	1–100
Actinomycetes	0.1–1
Fungi	0.1–1
Algae	0.01–0.1
Protozoa	0.01–0.1

decomposition of rocks and minerals, improvement in soil structure and stable aggregates.

The pH of soil governs the availability of nutrients as well as microbial composition. Generally, optimum pH for fungi and nitrogen fixing micro-organisms is < 5.5 or around 7.0 respectively. The organisms that inhabit soil have diverse activities, the greatest numbers are involved in the decomposition of plant materials. Micro-organisms can only be observed under an optical or electron microscope and their numbers is large (Table 21.1).

CLASSIFICATION OF SOIL ORGANISMS

Soil organisms can be classified as soil flora and soil fauna. The actions of

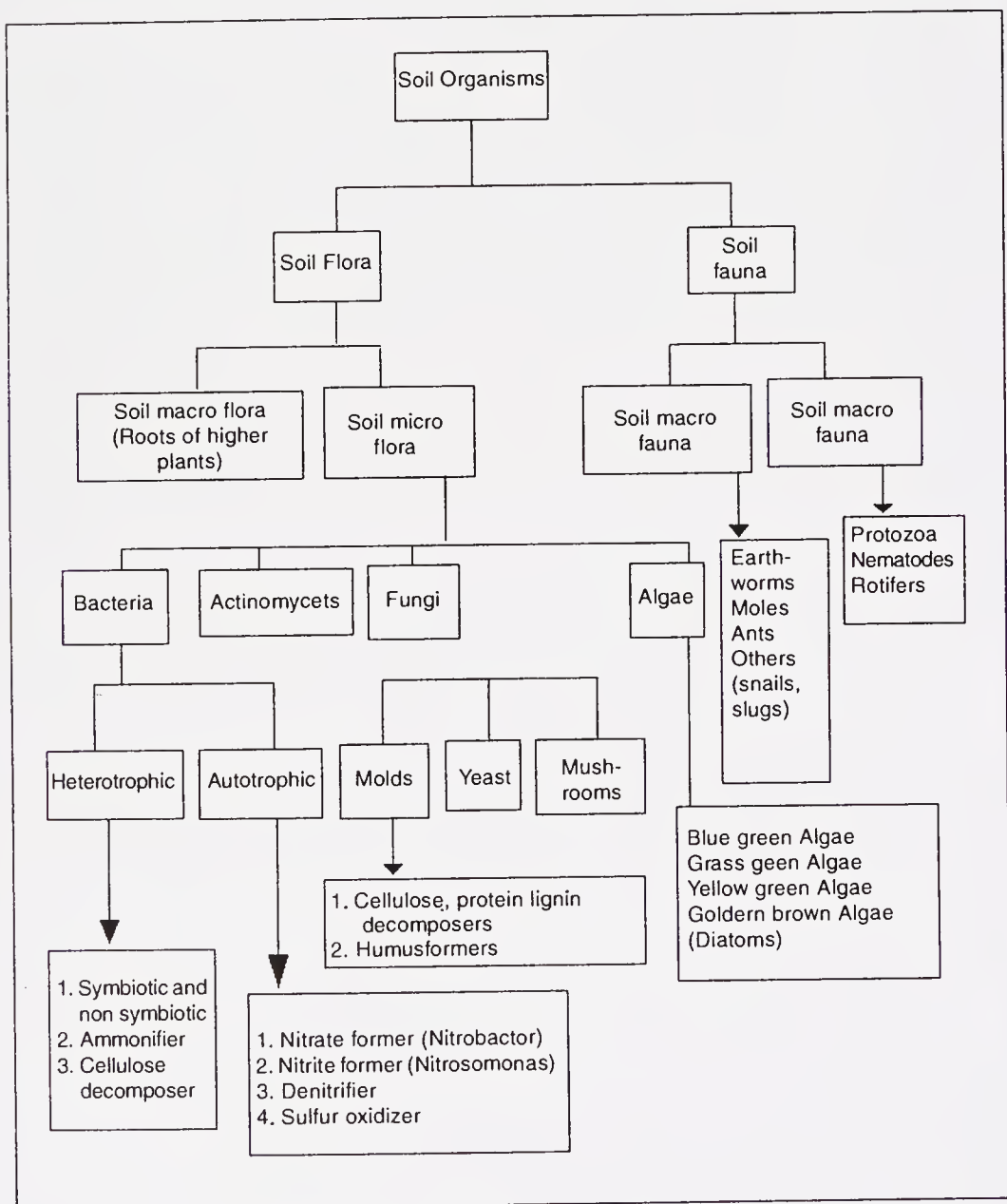


Fig. 21.1. Classification of soil organisms

microflora are chemical while that of fauna is both chemical as well as physical. Animals move in and into the soil. Earthworms incorporate the plant residues in soil. Larger animals like geophers, moles, dogs, rats burrow into the soil and bring about soil mixing and granulation. The principal soil organisms have been classified in Fig. 21.1.

Micro-organisms have been classified on the basis of morphology, shape, size, temperature sensitivity, and requirements of molecular oxygen, sources from which they derive carbon for cells synthesis and also special biochemical transformations they carry out. Based on their ability to grow in the presence or absence of molecular oxygen, micro-organisms are classified as aerobes and anaerobes respectively.

Classification Based on Temperature

The micro-organisms grow and develop within a certain range of temperature. Those which grow at temperature below 10°C are known as psychrophiles; those which grow between 20°C and 40°C are mesophiles, and those which can proliferate at higher than 45°C temperature are thermophiles.

Heterotrophs and Autotrophs

Based on the energy and carbon requirements for cell synthesis, soil micro-organisms are divided into two broad groups-heterotrophs and autotrophs. The heterotrophs derive their energy from oxidation of complex organic compounds, which also serves as a source of carbon. The autotrophs utilize carbon from carbon dioxide for cellular synthesis. The autotrophs are further subdivided into chemoautotrophs, which derive their energy from oxidation of simple inorganic compounds, and photoautotrophs, which derive their energy from sunlight.

DIFFERENT GROUPS OF SOIL ORGANISMS

Soil macro flora (roots of higher plants) perform following functions:

- Roots produce organic matter after their decomposition.
- Root exudates supply food and energy for soil animals and micro flora (bacteria, fungi, actinomycetes and algae).
- Plant roots encourage soil porosity and soil aggregation. Root exudes stabilize soil aggregates.

Soil Microflora

The micro-organisms inhabiting the soil can be classified into bacteria, actinomycetes, fungi, algae and protozoa. Different group of micro-organisms are discussed here:

Bacteria

Characteristics: Bacteria are single celled organisms. The cells of bacteria may be rod shaped or spherical. The rods are about 1 μm wide and up to 3 μm long, and cocci about 2 μm in diameter.

Population: Bacteria are the most dominant group of micro-organisms in

the soil. Their distribution in soils is not uniform and more population is found near the source of organic substrate. Near roots, population may be 100 times than in rest of the soil.

However, it is not easy to determine the total population of soil bacteria in any soil accurately. In general, horizon A of a soil profile consists of more micro-organisms than B and C-horizons. Under anaerobic conditions, bacteria dominate the scene and carry on the microbiological activities in the soil.

Different Types of Bacteria

- Autochthonous and zymogenous organisms: In 1925, Winogradsky classified soil bacteria into two broad categories-the autochthonous and the zymogenous organisms. The autochthonous or indigenous population remains more or less constant as they derive their nutrition from soil organic matter (e.g. *Arthrobactor*, *Nocardia*). Zymogenous or fermentative organisms derive their energy from the organic matter incorporated into the soil and thus it fluctuates depending on the availability of organic carbon. (e.g. *Pseudomonas* and *Bacillus*).
- Based on oxygen requirement: Bacteria may be distinguished into anaerobic, aerobic and facultative anaerobic, i.e. those capable of developing both in the presence and absence of oxygen.
- Based on temperature nutrition and energy:

Bacteria	Optimum temperature for their population and activities
Mesophiles	15–45°C – constitute the bulk of soil bacteria
Psychrophiles	<20°C
Thermophile	45–60°C

Autotrophs: synthesize their own food.

Heterotrophs: depend on prepared food for their nutrition

Photoautotrophs: synthesize their food using sunlight as the source of energy.

Chemoautotrophs: synthesize their food using energy from chemical reactions.

Obligate chemoautotrophs: those chemoautotrophs, which prefer specific substrates. Some examples are given below:

Bacteria	Substrate the bacteria utilize
<i>Nitrobactor</i>	Nitrite
<i>Nitrosomonas</i>	Ammonia
<i>Thiobacillus</i>	Converts sulphur compounds to sulphate
<i>Ferrobacillus</i>	Capable of converting ferrous iron to ferric iron

Classification based on symbiotic relationship

Symbiotic dinitrogen fixers: Associated with a host plant, both host and bacteria benefit. Fixes N_2 from atmosphere.

Non-symbiotic dinitrogen fixers: Bacteria present without the association of host, but fix N_2 .

Associative dinitrogen fixers: *Azospirillum* in association with roots of some cereals.

Role of Bacteria

- Bacteria participate in organic transformations.
- Bacteria carry out enzymatic transformations.
- They oxidize or reduce certain chemical reactions in soils. For eg, nitrification, sulfur oxidation, nitrogen fixation.

Actinomycetes

Characteristics: Actinomycetes reveal slender unicellular branched mycelium and clubbed with bacteria in the same class of schizomycetes but confined to the order Actinomycetales. On agar plates, they can easily be distinguished from true bacteria. Unlike slimy distinct colonies of true bacteria, which grow quickly, actinomycete colonies appear slowly, show powdery consistency and stick firmly to agar surface. All actinomycetes are heterotrophic, decomposing plant residues in soils and composts.

Population in soil: The number of actinomycetes increases in the presence of decomposing organic matter. The most conducive range of pH is between 6.5 to 8.0. Waterlogging of soil is unfavorable for the growth of actinomycetes whereas desert soils of arid and semi-arid zone sustains sizable population, probably due to the resistance of spores to desiccation. The percentage of actinomycetes in the total microbial population increases with the depth of soil.

Types of actinomycetes: Temperatures between 25 and 30°C are conducive for the growth of actinomycetes although thermophilic cultures growing at 55 and 65°C are common in compost heaps where they are numerically extensive. They mostly belong to the genera *Thermoactinomycetes* and *Streptomyces*.

Role of actinomycetes: (i) Actinomycetes are important in the decomposition of soil organic matter and liberation of its nutrients, (ii) Resistant compounds such as cellulose, chitin and phospholipids are reduced into their simpler forms.

Fungi

Characteristics: Soil fungi may be parasitic, saprophytic. Soil fungi possess filamentous mycelium composed of individual hyphae which are 5–20 μm in diameter and can be several centimeters in length. The hyphae may be uni-bi-or multinucleate, non-septate and septate.

Population in soil: The quality and quantity of organic matter present in soil have a direct bearing on fungal members in soil since most fungi are heterotrophic in nutrition. Fungi are dominant in acid soils because acidic environment is not conducive for the existence of actinomycetes or bacteria. This results in utilization of native substrates in soil by fungi. They are present in neutral or alkaline soils and some can tolerate pH beyond 9.0. Arable soils contain abundant fungi since they are strictly aerobic and excess moisture decreases their numbers.

Classification: Fungi are classified into *Phycomycetes*, *Ascomycetes*,

Basidiomycetes and *Fungi imperfecti*. The following are the genera of fungi which are most commonly encountered in soils and which can be isolated by conventional methods: *Acrostalagmus*, *Aspergillus*, *Botrytis*, *Trichoderma*, *Monilia*, *Penicillium*, *Cladosporium*, *Fusarium*, *Mucor*, *Cunninghamella*, *Rhizopus*, *Pythium* and *Rhizoctonia*.

Role of Fungi

- One of the primary functions of filamentous fungi in soil is to degrade organic matter and help in soil aggregation.
- Some of the fungi capable of forming ectotrophic associations on the root system of forest trees such as pine belonging to the genera *Boletus* and *Lactarius*, help in mobilization of soil phosphorus and nitrogen into plants.
- The saprophytic fungi are active decomposers of plant residues and can decompose all components of plant material.
- Basidiomycetes attack lignin, cellulose and related compounds.

Algae

Characteristics: The cells of soil algae are filamentous, 4-10 μm in diameter. Algae are photoautotrophs, that is, they are able to photosynthesize and therefore tend to be concentrated near the soil surface. Soil surface may become green.

Population: Algae population is 1–10 billion per square metre, 15cm deep (10000-100000 per gram soil). The mass of live algae in soils may range from 50-600kg ha^{-1} furrow slice.

Types: Soil algae are divided into four general groups; blue-green, green, yellow green and diatoms. Like algae they form lichens by forming an association with a fungus. Green algae are evident in non-flooded soils. Diatoms are found in old gardens. Both the green and the blue-green algae are much larger in number than diatoms.

Role of algae:

- i) They are important as primary colonizers of mineral debris because of their photosynthetic ability, which produces organic materials for micro-organisms.
- ii) Algae produce polysaccharides, which aggregate soil particles and thus help to stabilize soil surface against erosion. This stabilization and nutrient accumulation by alga cells creates favorable conditions for colonization by higher plants. Surface of algae is protected from desiccation by a fungus in association with it. This is called lichen. Lichens are sensitive to air pollution especially in the presence of SO_2 .
- iii) The effect of algae on plant growth can be summarized as follows:
 - a) Adds organic matter to the soil. This increases nitrogen content of surface soils and an increase in soil fertility.
 - b) Improves soil aeration – especially in rice fields.
 - c) Blue green algae (cyanobacteria) fix atmospheric nitrogen. Like algae they form lichens by forming an association with a fungus.

Fungi

Fungi may be classified as molds, yeast and mushrooms:

Molds: Molds are filamentous, microscopic fungi. Molds develop vigorously in acid, neutral or alkaline soils. They play important role in decomposing organic residues in acid forest soils. *Penicillium*, *Mucor*, *Fusarium* and *Aspergillus* are common genera of molds. Their numbers fluctuate greatly with soil conditions. 10–100 billion/m² 15 cm deep represents a normal range of their population.

Yeast: Yeast is a group of fungi, which, exist as unicellular organisms. They reproduce by fission or budding. They are used for the production of alcoholic beverages and as food supplement. Yeast causes different diseases in plants. Yeast is not common in soil.

Mushrooms: Mushroom fungi are found in forests and grasslands where there are ample moisture and organic residues. Some of the mushrooms are edible. The fruiting body, which is above ground, is small part of total organisms. Mushrooms are grown on organic materials and manure is provided as source of their food. Mushrooms are not common inhabitant in soil.

Soil Micro Fauna

Protozoa

Characteristics: Protozoa are single-celled organisms, which feed on bacteria. The cells of soil protozoa are generally less than 50µm in diameter. They are mobile and move in soil pores where there is sufficient thickness of water. Under dry conditions they form cysts which are resistant to desiccation.

Population: The live weight of protozoa in soils is 15 to 175 kg ha⁻¹ furrow slice. Isolation and quantification of soil protozoans involve time consuming procedures.

Types in soil: More than 250 species have been isolated in soils.

Role of protozoa

- i) Their main function in soil ecology appears to be in the control of the size of bacterial populations.
- ii) They liberate nutrients by feeding on bacteria.
- iii) Application of organic manure increases the number of soil protozoans which is a reflection of the corresponding increase in the bacteria flora due to application of organic matter.

Nematodes

Nematodes are found in almost all soils. They are microscopic. More than 120 species of nematodes are known. Most nematodes feed on bacteria and fungi. Nematodes live on decaying organic matter. They are called saprophytes. Nematodes are also predators on other nematodes, bacteria, algae, protozoa. Some nematodes, which can infest on the roots of plant species, are called *Heterodera*.

Rotifers

About 100 species of rotifers are known. They thrive under moist condition, especially in swampy land. Rotifers are microscopic in size. Their anterior is modified into a retractile disk bearing circles of cilia which, in motion, give the appearance of moving wheels.

Soil Macro Fauna

Earthworms

The total nutrient requirement in the present context (2000-1) amounts to 35.26 million metric tons. The production of these nutrients by industries is limited to around 20.1 million metric tons. The gap is around 16.16 million metric tons and has to be bridged through other sources like organic manure, which include crop residues as a major input component in soil fertility management. Here the role of earthworm assumes greater relevance as a supercomposter by mixing materials.

About 1800 species of earthworms are known and 293 species of the genus *Pheretima* were reported (Stephenson 1930) which are mostly found in South East Asian Countries. The common types of earthworm found in India are : i) *Pheretima posthuma*, ii) *Pheretima elongata*, iii) *Pontoscolex corethrurus*, iv) *Lampita mauritii*, v) *Ocnerodrilus occidentalis*, vi) *Dichogaster bolani*, vii) *Dichogaster curgensis*, viii) *Perionyx excavatus* and ix) *Eutyphoeus waltoni*. The population of earthworm may vary from 1,25,000 to 1000,000/ha. They are active during three to four months of monsoon in tropical situation. The worms prefer organic matter as their food including fresh and decaying leaves, larvae and small animals, living or dead and the bacteria mixed with earth. These worms ingest soil in large quantity, which passes through the alimentary canal which, consists of mini-grinder gizzard. The ingested soil and organic matter mixed thoroughly is ejected in the soil in the form of castings. They make crores of burrows every year, which make soil porous, increase aeration and infiltration rate of soil. These worms assimilate nematodes and destroy photopathogenic fungi and increase N-fixing bacteria. The soil is enriched with casts containing beneficial microorganisms, enzymes such as proteolases, amylases, lipase, cellulase and chitinase and help decomposition of organic matter even after the cast is excreted. Thus, the soil fertility is enriched.

Earthworm (belong to phylum Annelida) feed on animal and plant residues. They excrete the ingested materials (organic matter and soil). This excreted material becomes a source of plant nutrients. *Lumbricus terrestris* is one of the commonly occurring species of earthworms. It occurs in soil between pH range of 4 to 7. Earthworms prefer moist well-aerated warm (21°C) soils. The formation of casts on the soil surface is due to a few species of *Allolopophora*. The casts include partly digested plant material. They have lower C: N ratio, thus accelerating formation of mineral nutrients for plants.

Earthworms Perform Important Functions in the Soil

- Several species create channels, which act as transmission pores for water.
- Some earthworms live on surface soil, compost and manure heaps. They bring about a transportation of fertile soil mass from sub-soil to the surface layer.
- Earthworms make holes into the soil through burrowing.
- Activities of earthworm have been found to improve crop yields significantly. Yield of maize and rice crop improved significantly with earthworm inoculation. (Lavelle *et al.* 1994).
- Significant changes in soil fertility have been obtained. Bulk density of soil,

N mineralisation and water regimes exhibited a significant effect of earthworm inoculation (Lavelle *et.al.* 1994).

Earthworm's Population in Soil is Adversely Affected Due to

- Use of heavy farm machinery, sandy, salty, hot or cold, bare or barren soils, very acidic soils, toxic insecticides.
- Mice, moles and mites are enemies of earthworms.

Moles, Ants and others

Mites, centipedes, insects, ants and termites belong to phylum Arthropods. They are joint footed invertebrate organisms. They feed on decaying vegetation and increase soil aeration with their burrows. The ants and termites can modify soil structure and till the soil.

Snails, Slugs

They feed on decaying vegetation but will eat and damage living plants.

METHODS OF STUDYING SOIL ORGANISMS AND THEIR ACTIVITIES

Some of the important and commonly used methods for the isolation and study of soil micro-organisms are discussed below.

Obtaining Soil Samples

Soil samples are collected normally up to a depth of 15 cm. At least 10–25 g of soil is taken as a representative sample.

Soil dilution and plate counts: These have been used for isolation of soil micro-organisms. Appropriate soil dilutions (1-ml aliquots) are plated on suitable solid media for this purpose. Incubating dilution plates in an incubator adjusted to 55–60°C usually isolates thermophilic micro-organisms (capable of tolerating higher temperatures). In this method it is likely that some micro-organisms may still stick to the surface of soil particles in the form of hyphae in spite of shaking soil samples in water to bring them into suspension.

The soil plate method: A small quantity of soil (0.005–0.01 g) is directly placed in petri plates and crushed with a needle. Pouring of melted and cooled agar medium follows this. In certain cases, a crumb of soil (up to 1 cm) has been used to study soil micro flora.

The buried slide method: A glass slide is introduced in soil and left for 2 to 3 weeks. The slide is then removed in such a way that one of its side is not disturbed. This side is washed in a stream of water, air-dried and fixed over a low flame. The slide is placed over a steam bath and stained in rose Bengal, dried and examined under a microscope. The technique is useful to study qualitative changes in soil microflora under the influence of soil amendments.

Enrichment cultures: This method is based on the nutritional requirement of a particular group of microorganisms. Thus heterogeneous inoculum when added to a liquid medium, organisms, which are adapted to the nutrients available in the medium, start growing. This helps in the isolation of iron and sulphur oxidizing micro-organisms and those that utilize nitrate.

Direct microscopic examination of soil: This method helps in the quantitative determinations of the microorganisms and their inter relationship. The slide is prepared by transferring one gram of soil mixed with 0.015 per cent agar solution. The suspension is poured over 4 cm² area of the slide with the help of a needle. The slide is placed on a water bath and stained with rose Bengal. The number of micro-organism's per/g soil is calculated.

Soil respiration: This method is based on the fact that CO₂ is produced when substrate-containing carbon is oxidized. The amount of CO₂ produced is taken as an index of the total activities of soil organisms.

Soil percolation techniques: This is based on the principal that a substrate is degraded when incorporated in soil due to stimulation in the number and activities of soil organisms.

Soil enzymes: Soil micro-organism produces a number of enzymes during their metabolism. Thus, the activity of chosen enzymes can give an indication of the total activities. Oxidation-reduction and hydrolytic type of reactions are commonly made use in soil enzyme studies.

Besides the above methods different techniques for isolation of bacteriophages, algae, cyanophages and protozoa are used.

FACTORS AFFECTING SOIL ORGANISMS

Soil organisms depend entirely on soil for their nutrition and growth. The factors which influence microbial activity in soil are as follows.

Soil Water

- Water is the major component of protoplasm in a microbial cell and is essential for growth of soil organisms.
- At low moisture content soil water is strongly adsorbed on clay particles and may not be available to microorganisms. Concentration of available nutrients in soil is affected to a large extent by moisture content.
- In the presence of excess water, the environment becomes anaerobic, thus aerobes become suppressed and inactive and anaerobic bacteria dominate. In the absence of adequate water in soil, some of the microbes die due to tissue dehydration and some of them change their form into resting stage of spores or cysts. Microorganisms are less active at the wilting percentage of plants. Anaerobes, comprising a very small portion of soil microbes, grow best at saturated or waterlogged conditions. However, majorities of soil microorganisms are most active when soil moisture is 0.33 to 1 bar. (20 to 50% soil moisture)
- Under dry conditions, bacteria may form spores, which can resist the drought conditions. Several microorganisms like actinomycetes prefer dry conditions.

Soil Temperature

Soil temperature is the most important environmental factor influencing the biological processes and microbial activity. The optimum temperature range at which particular micro-organism grows and functions actively is rather narrow. Most of the soil organisms are mesophiles. There are generally three groups based on temperature as psychrophiles, mesophiles and thermophiles.

Soil Air

Microbes consume oxygen from soil air and give out carbon dioxide. Oxygen in soil is renewed through the process of diffusion and mass flow from atmospheric air. In the absence of gaseous exchange, CO_2 accumulates in soil air and become toxic to the microbes. Free living nitrogen bacteria as well as symbiotic forms are known to be more active in well-aerated soil. Soil air is influenced by moisture level of soil.

Soil Reaction or pH

The majority of soil organisms especially microorganisms grow best at neutral soil reactions (pH 7.0) which, is the pH of microbial cytoplasm (the cell material). Bacteria, in general, prefer near neutral to slightly alkaline reaction between pH 6.5 and 8.0; fungi grows in acidic reaction between pH 4.5 and 6.5; actinomycetes prefer slightly alkaline conditions. Soil pH influences the soil enzymes and plays an important role in microbial activity.

Light

Direct sunlight is injurious to most of the micro-organisms except algae.

Soil Organic Matter

Soils having moderate to high organic matter are most favorable for the optimum growth and development of most of the soil organisms. Organic matter being the chief source of energy and food for soil organisms has a great influence on their population. Soil organic matter varies in different soil types. Desert sandy soils are very low in organic matter (<0.5%) as compared to marshy soils (>50% organic matter). The source of energy rich material is an essential requirement for micro-organisms and absence of such materials in soil reduces microbial activity. Heterotrophs obtain their energy and carbon for cell synthesis from reduced carbon substrates. Thus, well-aerated soil rich in organic matter is an essential prerequisite for maximum number and activity of heterotrophic microorganisms.

The Soil and its Fertility

Physical, chemical and physico-chemical characteristics of soil and its nutrient status influence the microbial population. A soil in good physical condition has good aeration and water supplying capacity, which are so essential for optimum microbial activity. The availability of N, P, K for plant growth determines the fertility level of soil. Soil micro-organisms also needs essential elements. Also, soil micro flora has great influence on fertility level. Application of fertilizers improves the microbial activity because of the availability of more readily available nutrients. However, some fertilizers may have inhibitory effect on specific organisms. For example, addition of nitrates inhibits the activity of free living nitrogen fixing bacteria like *Azotobacter*. Some autotrophic bacteria are encouraged by the addition of fertilizers. Micro-organisms have greater demands for nutrients for their growth and development, especially for N, P, S and Ca.

Microbial Products

Some antimicrobial retard or kill other beneficial micro-organisms in the soil. Besides, the competition for nutrients among different microbes can also be eliminated and thereby a particular micro-organism gains more nutrients and consequently increases its activity.

Ecological Factors

Different group of micro-organisms exists in soil, which are in dynamic equilibrium. This equilibrium is attained in due course of time even if some pathogens enter in soil and disturb the balance temporarily. The presence is further based on different type of relationship amongst microbial population in soil. For example. (i) Fungi may suppress the growth of soil organisms, especially when soil pH is low. (ii). Organisms capable of growing under darker conditions would predominate in deeper layers, (iii). In some case nematicides, bactericides and fungicides might be added to the soil to kill some undesirable organisms. Thus the microbial balance may be upset and in course of time the equilibrium may be restored.

Cultural Factors

- Different organisms are stimulated in the soil due to different plant species and their chemical composition.
- Different chemical substances excreted by plant roots influence microbial activity.
- Roots and plant parts left over in the field, form rich nutrients for the microorganisms.
- Crop rotation with different plant species brings about different stimulatory effects on the microflora. Different root system of species, i.e. deeper or shallow brings about physical and chemical changes in soil.
- Tillage operations and other cultural practices affect soil and consequently soil micro flora.
- Application of green manure stimulates some bacteria, actinomycetes and fungi. This may be attributed to increased organic matter level, physical and chemical soil conditions.
- Burning of the topsoil by adding organic waste results in partial sterilization of the soil. Harmful, organisms like protozoa are killed and bacterial population is increased.
- Spraying of crop plants with pesticides, plant growth regulators have some effect on soil microflora. The chemicals may fall on the soil and may influence bacterial population directly.

MICROBIAL INTERACTION

A microbial population may contain a number of the same species or a number of similar species. When different populations are present and interacting, this is called a community. The communities and their interactions constitute an ecosystem. The sum of all the environmental and organism characteristics determines the role of a population in relation to others. In natural environment,

a number of relationships exist between individual cells. A number of possible interactions may occur between two species. Campbell (1983) has presented the relations in Table 21.2.

The above relations may be categorized as:

Effect	Type of interaction
No effect	Neutralism
Beneficial effects	Commensalism, Synergism, Mutualism, Symbiosis
Harmful effects	Competition, Amensalism, Predation and Parasitism

Table 21.2. Microbe-microbe relationship (Between two individuals or populations of micro-organism A and B).

Relationship (interaction)	Loss benefit account	Example
Neutralism	No effect A $\leftarrow$ B	A and B in different habitat or at very low population levels.
Commensalism	No effect Benefits A $\leftarrow$ B No effect	A produces vitamin for B
Synergism	Benefits A $\rightarrow$ B Benefits $\leftarrow$	Not obligatory, exchange of metabolites in green-sulfur bacteria/sulfur reducer consortia, complimentary enzyme systems in polymer degradation.
Mutualism	Benefits A $\rightarrow$ B	Usually obligatory dependence of organisms. Bacteria N-fixing root nodules, Lichens.
Competition	Benefits $\leftarrow$ Harms A $\rightarrow$ B Benefits $\leftarrow$	Both A and B using same limited food source.
Amensalism	Harms A $\rightarrow$ B	A produces antibiotic which harms B.
Predation	No effect Eats A $\rightarrow$ B	A (a protozoon) eats B (a bacterium). A usually larger than B.
Parasitism	Benefits $\leftarrow$ Harms A $\rightarrow$ B Benefits $\leftarrow$	A lives on or in B and uses B as a food source. A usually smaller than B. B may not be killed

Commensalism: Commensalism means only one species derive benefits while the other are unaffected. One of the most important beneficial associations is that involving two species, one of which can attack a substrate not available to the second organism, but the decomposition results in the formation of products utilized by the second. This type of commensalism occurs frequently in nature. Thus, polysaccharides are transformed to nutrients supporting non specialized microorganisms. e.g. cellulolytic fungi produce a number of organic acids from cellulose.

Synergism: An association of mutual benefit to the two species but without the cooperation being obligatory for their existence or for their performance of some reaction. For example, in a medium deficient in nicotinic acid and biotin, neither *Proteus vulgaris* nor *Bacillus polymyxa* will multiply as the former bacterium requires nicotinic acids and the later, biotin.

Symbiosis: Symbiosis expresses the living together of two organisms. Symbiosis means the two symbionts relying on one another and both benefiting by the relationship. Symbiotic associations are evident in soil among several groups of organisms: algae and fungi in lichens, bacteria residing within protozoan cells, bacteria and roots in the Rhizobium-legumesymbiosis and roots in the mycorrhizae.

Mutualism: It implies obligatory dependence of organisms.

Competition: Detrimental effects of one species upon its neighbors are quite common in soil. Competition means a condition in which there is a suppression of one organism as the two species struggle for limited quantities of nutrients. Competition may be seen between *Rhizobium* strains derived from soil and those applied with legume seeds at the time of sowing. The better competitor invades the root hairs more frequently and is responsible for high percentage of the nodules.

Amensalism: Alteration of the environment to the detriment of the certain microbial groups may occur through the synthesis of metabolic products that inhibit or kill microbial cells by the utilization of O₂ or by producing antibiotics. An antibiotic is a substance formed by one organism that in low concentration inhibits the growth of other organism. The most frequently encountered bacteria synthesizing antibiotics are species of *Bacillus* and strains of *Pseudomonas* that liberated pyocyanin and related compounds. Species of *Penicillium*, *Aspargillus*, *Trichoderma*, *Fusarium* and other fungi also excrete antibiotic substances.

Predation and parasitism: Predation is one of the more dynamic inter relationship among micro-organisms in nature. Predation and parasitism are observed in the feeding of bacteria by protozoa, the attack of nematodes by predacious fungi, the digestion of fungal hyphae by bacteria and lysis of bacteria and actinomycetes by bacteriophage.

Neutralism: Neutralism means two micro-organism behave entirely independently.

SOIL PLANT INTERACTION - RHIZOSPHERE PLANT PATHOGEN PHYLLOSPHERE, MYCORRHIZA

Soils differ in their physical, chemical and biological properties. There exists a certain specific relationship between soil plant and micro-organisms. Man

interferes in this relationship directly through agricultural practices and indirectly through his socio-economic activities. Micro-organism in soil also influences the plant. Thus in a given location, the interactions between the soil, plant and micro-organism become distinct and dynamic.

Soil, is a medium in which plant and animal residues are decomposed and various biological process are carried on. During this process, several pathogenic forms of microbes are suppressed and eliminated when incorporated in the soil. Various plant species which are supported by soil have evolved various genetic characters. Thus different species and varieties with different characteristics exist in nature. These characters include differences in height, foliar spread, physiological conditions and morphology of their root system. The growing plants in turn influence soil properties. It improves soil fertility through addition of crop residues, resulting in the increased microbial activity. Thus an intricate relationship between the plant root and soil systems develops and functions in a dynamic equilibrium in a given location and biosphere. Any change in the growth pattern of the plant or the soil qualities alters the equilibrium. Existence of micro-organisms in nature further adds to the complex relationship between soil and plant. Micro-organisms being intimately associated with root system help the plants to obtain nutrients from the soil. In other words, the efficiency of the plant in absorbing the nutrients from the soil is also dependent on the associated microorganisms.

Rhizosphere

(i) The term 'Rhizosphere' is used to denote the region of the soil, which is subject to the influence of plant roots. Rhizosphere is characterized by greater microbial activity than the soil away from plant roots. Rhizosphere region is a place of interaction involving plant roots, soil microbes and plant pathogens. (ii) The term 'rhizosphere effect' indicates the overall influence of plant roots on soil micro-organisms. It is now recognized that the 'rhizosphere effect' is due to the exudates from the roots, which attract some micro-organisms. Spraying the plants with certain organic substances can also influence the effect, or by altering the soil conditions particularly the soil aeration and fertility level. (iii) It is now clearly established that greater number of bacteria, fungi and actinomycetes are present in the rhizosphere soil than in non-rhizosphere soil. Other organisms like nematodes, protozoa and algae are also known to be stimulated in the rhizosphere region but to a lesser extent. Soil bacteria influence rhizosphere more than actinomycetes and fungi. (iv) There is an increase in the exudation of organic acids, amino acids and monosaccharides by plant roots in the presence of micro-organisms. (v) The number of motile bacteria, ammonifiers, fermenters, cellulose decomposers, oxygen consumption and CO₂ production increases in the rhizosphere region. (vi) Various groups of nutritional bacteria differ in the rhizosphere than from the soil in two ways. First, there is a preferential stimulation of organisms, which demand amino acid for their maximum growth. Second, there is a lower relative incidence of bacteria depending upon nutrients available from soil. Micro-organisms also influence root hair development, mucilage secretion and lateral root development of several plants. (vii) Secretion of antibiotics by micro-organism and the resultant biological inhibition of growth

of other susceptible microorganisms are demonstrable.

It is now recognized that the rhizosphere effect is due to the exudates from the roots, which attract some micro-organisms. The width of the zone in soil thus influenced by the roots and varies with the plant species, its age, cultural conditions, soil conditions, environmental conditions etc. The effect can also be artificially influenced to some extent by spraying the plants with certain mineral elements or organic substances, or by altering the soil condition, particularly the soil aeration and fertility level.

R: S Ratio

It is the ratio between the microbial population in the rhizosphere (R) and in the soil (S) further apart. The R:S ratio :

- Gives a good picture of the relative stimulation of the micro-organisms in the rhizospheres of different plant species.
- It can be applied to different group of organisms in the rhizosphere in order to compare the stimulation of micro-organisms by the root.

Factors Influencing Rhizosphere Effect

The 'rhizosphere effect' may be influenced by several factors:

- Rhizosphere effect declines with increasing distance between rhizosphere and soil apart.
- **Legume rhizosphere:** Increase in number of bacteria in legume rhizosphere is over hundred times as compared to non-legumes.
- The rhizosphere effect is found to be more at the time of flowering than the seedling stage of the plants.
- In general, rhizosphere effect was near the maximum just prior to flowering.
- In general, the maximum effect was found in sandy soils and least in humus soils.
- The rhizosphere organisms are more when soil moisture is low.
- The effect of rhizosphere population is more through plants, which get the benefit of fertilizer application. Well-fertilized plants stimulate more organisms in soil.

Plant Pathogen Rhizosphere

Plant pathogen have several influences on plant growth

- Importance of root exudates is of paramount importance. Spores of many fungi such as *Fusarium*, *Sclerotium*, *Nectricillium* etc. have been shown to germinate by the stimulus provided by the root exudates of the host plants. The compounds exuded by plant roots help to overcome the static nature of dormant reproductive structures in soil. For example, roots of *Allium* release certain volatile stimulators which help release fungistasis of sclerotia of *Sclerotium cepivorum*.

Root exudates provide food base for the growth of antagonists, which could suppress the growth of pathogenic micro-organisms in soil. For example, more number of *Streptomyces* and *Trichoderma* occur in resistant varieties than those which were susceptible. Tomato resistant to wilt contained high

incidence of *Trichoderma viride* in its rhizosphere which minimizes the severity of wilt on susceptible plants.

- Root exudates containing toxic substances such as glycosides and hydrocyanic acid may inhibit the growth of pathogens. For example, Bison (a flax variety) is resistant to *Fusarium* due to presence of hydrocyanic acid in its root exudates.
- Virus infected plants which result in stunting could be restored to normalcy by spraying the leaves with thiouracil or gibberellins which are known to overcome stunting symptoms. This is because of change in numbers of microorganisms in the rhizosphere accompanied by alterations in the incidence of amino acid and vitamin requiring bacteria.
- Root exudates play a role in neutralizing soil pH, altering the microclimate of the rhizosphere through liberation of CO₂ and H₂O. These changes may influence infection of roots by pathogenic fungi.

The Phyllosphere

The exposure of plant parts to dust and air currents results in the establishment of a typical flora on their (plant) surfaces aided by the cuticle, waxes and appendages. This helps in providing anchorage for micro-organisms. These surfaces (say leaves) provide materials which are rich in amino acids, glucose, fructose and sucrose, collectively called 'leaf diffusates'. These leaves, surfaces have been termed as phylloplane and the zone of leaves inhabited by micro-organisms as phyllosphere.

Organisms on Phyllosphere

- Nitrogen fixing bacteria such as *Beijerinckia* and *Azotobactor* are dominant on leaf surfaces under forest vegetation.
- Genera such as *Pseudomonas*, *Pseudobacterium*, *Xanthomonas*, *Sarcina* have also been encountered on plant surfaces, especially on leaf surface.
- A few fungi and actinomycetes have also been found on plant surfaces. It includes a few species of *Cladosporium*, *Helminthosporium*, *Penicillium*, *Fusarium*, *Mucor*, *Aspergillus*, *Trichoderma*, *Actinomycetes* and *Streptomyces*.

Beneficial Effects of Phyllosphere

- The presence of spores of a pathogen on the surface of leaves and pods results in the formation of a substance referred to as phytoalexin (Greek word phyto means plant; alexin means warding off compound.) It may control the spread of air borne pathogens inciting plant diseases. The fungal metabolite may also independently induce phytoalexin formation.
- Epiphytic micro-organisms are known to synthesize indol acetic acid.
- Fixation of nitrogen by micro-organisms is an important biological function.

Use of Elicitors

Elicitors are the compounds, which induce the synthesis of phytoalexins. It includes polysaccharides from fungal and plants cell walls, lipids, microbial

enzymes and polypeptides. It has been observed that spraying of leaves with aqueous solutions of sucrose or with bacterial suspensions has resulted in enhanced growth and yield of legumes. It is believed that sprays may have intensified the biochemical transformations beneficial for phyllosphere.

Mycorrhiza

The symbiotic association between fungi and root system of higher plants comes under the name mycorrhiza which literally means fungus root.

The algae synthesize carbohydrates through their chlorophyll and supply them to the fungi. Fungi on the other hand, help in preparing nitrogenous substances for the growth of algae. Fungi are mostly found in the form of mycelial strands in roots of higher plants. They are known as mycorrhizae. The host and the fungus live in intimate symbiotic relationship. It is presumed that mycorrhiza aid the host plant in the adsorption of certain nutrients.

Types

Ectomycorrhiza: The fungus forms a compact mantle over the root surface and the hyphae grow out into the soil.

Vascular arbuscular mycorrhiza: The vesicular arbuscular (VA) mycorrhizae is also a type of mycorrhizae characterized by the group of fungi involved and by the host plants they infect. The VA mycorrhizae have a loose net work of hyphae in soil and an extensive growth within the cortex of the plant. In the host cells they produce highly branched hyphal structures, called arbuscules and also vesicles. They are found in a wide variety of host plants, including most of the crop plants. The fungi involved are *Glomus*, *Acaulospora*, *Gigaspora*, *Sclerocystis*, *Entrophospora* and *Scutellospora*. The mycorrhiza have been observed to improve plant growth through better uptake of P and Zn from soil. The VA mycorrhizal fungi penetrate the outer most cortex region, when the plant is well supplied with phosphorus, but in phosphorus-deficient plants they penetrate deep into the cortex and help the plant to obtain the nutrient from the soil. VA mycorrhizal fungi are reported to increase the availability of water to plants.

Ericoid mycorrhiza: The ericoid mycorrhiza is seen in members of heath family like blueberry and Erica. *Pezizella ericae*, an ascomycete, is the most common fungal symbiont, which can be cultured.

Orchidaceous mycorrhiza: All orchids are infected at some stage in their life cycle by the orchidaceous mycorrhizal fungi. Artificial inoculation of orchids with the mycorrhizal fungus is not necessary, as the fungus is abundantly present in nature.

MANAGEMENT OF RHIZOSPHERE

Management of rhizosphere microflora may be done by

Bacterization

Artificial inoculation of seed or soil with preparation containing live microorganisms, especially bacteria. Microbial seed inoculants such as *Azotobactor*,

Beijerinckia, *Rhizobium* or *P-solubilizing* micro-organism may help in the establishment of beneficial micro-organisms in the rhizosphere in the immediate vicinity of growing roots. Field experiments have shown that the counts of *Azotobacter* in wheat rhizosphere increases upon artificial seed inoculation indicating the efficiency of bacterization as a means of altering and improving the rhizosphere microflora. There is an increase in germination due to *Azotobacter* inoculation. This is attributed to growth promoting substances excreted by the bacterium. Gibberellins and similar substances are produced by bacterial genera occurring in the rhizosphere, such as *Azotobacter*, *Arthrobacter*, *Pseudomonas*, and *Agrobacterium*. There is an increase in the amino acid, auxins, gibberellins and antibiotics content in plants grown in soil inoculated with specific micro-organisms.

Application of nutrients

Addition of NPK fertilizers on microflora causes a decrease as well as increase in the R:S ratio. Foliar sprays of urea are known to alter the number and nature of micro-organisms in the rhizosphere. Extensive studies have been done on induced changes in the rhizosphere micro-flora by foliar sprays of antibiotics, growth regulators, pesticides and inorganic nutrients in the hope that such approach may serve as a new tool in the biological control of root diseases.

Other Management Practices

Inhibition of pathogens in the rhizosphere and use of soil fungiasts: Fungistasis means inability of spores to germinate even under most favorable conditions. The effect of fungistasis may be attributed to the secretion of antibiotics by micro-organisms. Excessive inhibition of *Azotobacter* or *Rhizobium* in the root region because of secretion of antibiotics by micro-organisms may lead to decreased nitrogen fixation or nodulation.

Significance of root exudates: The fungi inhabiting the surfaces of roots influence the amount of substances absorbed into the root system. There is an increase in the exudation of organic acids, amino acids and mono saccharides by plant roots in the presence of microorganisms. Root hair development, mucilage secretion and lateral root development is influenced by microorganisms. Plant roots exudes contain organic substances like amino acids, sugars, organic acids, vitamins, nucleotides and other substances. This adds to rhizosphere effect. Root exudates influence the proliferation and survival of root infecting pathogens in soil by inhibition of pathogen in the rhizosphere. This may be achieved through use of soil fungiasts.

BIOLOGICAL NITROGEN FIXATION

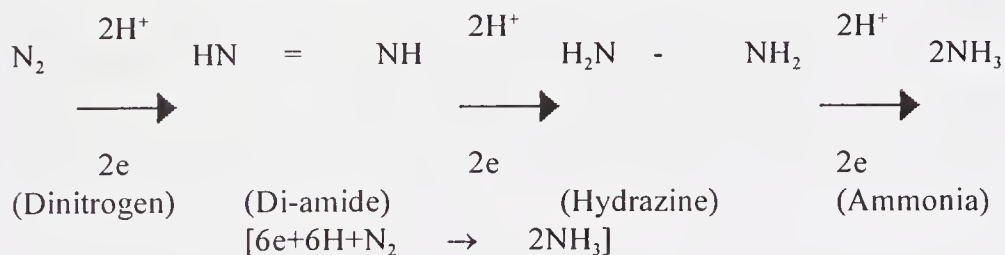
Biological nitrogen fixation is the biochemical process by which elemental nitrogen is combined into organic forms. Bacteria actinomycetes and blue-green algae (cyanobacteria) carry it out.

Non Symbiotic Nitrogen Fixation

The free-living bacteria have the ability to fix molecular nitrogen. *Azotobacter*

and *Clostridium* are the most important. *Azotobacteraceae* families of bacteria constitute the majority of heterotrophic free living nitrogen fixing bacteria. They include genera *Azotobacter*, *Beijerinckia* and *Derxia*.

Among the different nitrogen-fixing bacteria, *Clostridium*, and *Azotobacter* are the most intensively investigated genera. The overall reaction in the enzymic reduction of atmospheric nitrogen to ammonia could be postulated as follows:



Cell free extracts of *Azotobacter* and *Clostridium* could fix nitrogen in the same way as the free-living intact bacterial cells. The enzyme is responsible for the adsorption and reduction of N_2 gas.

Blue-green algae also constitute an important group of micro-organisms capable of fixing atmospheric nitrogen. Most of the nitrogen fixing blue-green algae belong to the orders *Nostocales* and *Stigonematales*. In general, nitrogen fixation is associated with forms possessing heterocysts.

Symbiotic Nitrogen Fixation

From the standpoint of agriculture, the most important nitrogen-fixing agent is associated with root nodules of leguminous plants. Bacteria belonging to the genus *Rhizobium* live freely in soil and in the root region of both leguminous and non-leguminous plants. They can enter into symbiosis with leguminous plants, by infecting their roots and forming nodules on them. In the legume root nodules symbiosis, the legume is the bigger partner while the *Rhizobium* is the smaller partner, often referred to as 'microsymboints'.

Usually certain strain forms nodules on a limited group of plants. Such a collection of strains is called cross inoculation group. Following species of *Rhizobium* have been recognized in this group of bacteria.

Physiology of Nodule Formation

- A. B. Frank in 1890 found that the roots of Leguminosae secreted a substance, which attracted the bacterium. The stimulation of infected cell takes place perhaps due to secretion of some chemicals like indol-acetic acid by the bacterium.
- Virtanen (1929) reported that infection occurred through amyloid spots at the root tips of young root hair. (i) The bacteria entered the young root hair, an infection thread is formed which grows towards base, and results in the nodule formation because of the division of pericycle cells or cells adjoining endodermis. (ii) At first, the entire nodule tissue is meristematic, but soon the infection thread branches and invades cells in all directions. (iii) The infection thread is enclosed in a cellulolytic membrane with pectic substance and it is believed that these membranes are from the host tissues. The infection

Table 21.3. Cross inoculation group of Rhizobium

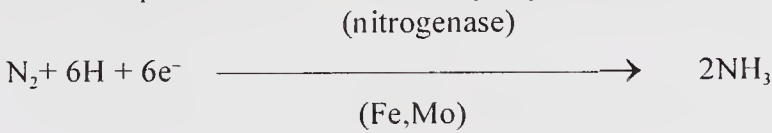
<i>Rhizobium</i> spp.	Cross inoculation grouping	Legume types
<i>R. leguminosarum</i>	Pea group	Pisum, Vicia, Lens
<i>R. phaseoli</i>	Bean group	Phaseolus
<i>R. trifolii</i> c	Clover group	Trifolium
<i>R. meliloti</i>	Alfalfa group	Melilotus, Medicago, Trigonella
<i>R. lupini</i>	Lupini group	Lupinus, Orinthopus
<i>R. japonium</i>	Soybean group	Glycine
<i>R. sp.</i>	Cowpea group	Vigna, Arachis

thread soon liberates bacteria into the cytoplasm of the host cell. The bacteria multiply and often fill the entire cell. (iv) After the nodule formation, vascular bundles are formed, inside which the bacterium establishes contact with host bundles. As the young nodule develops, the vascular bundles are differentiated into nodule cortex and get connected with the vascular system of the host root. (v) As the plants mature, the nodules become brown, the bacteroids disappear, and the nitrogen released for use by the plant. In the final stages, the nodule is cut off from the root by means of a cork layer.

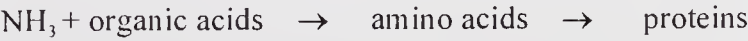
The energy requirement for biological nitrogen fixation appears to be high, and this becomes a limiting factor in the quantity of N- fixed in different legume–Rhizobium combinations.

Mechanism of Nitrogen Fixation

Biological nitrogen fixation is performed by a number of organisms. The overall effect of the process is to reduce nitrogen gas to ammonia.

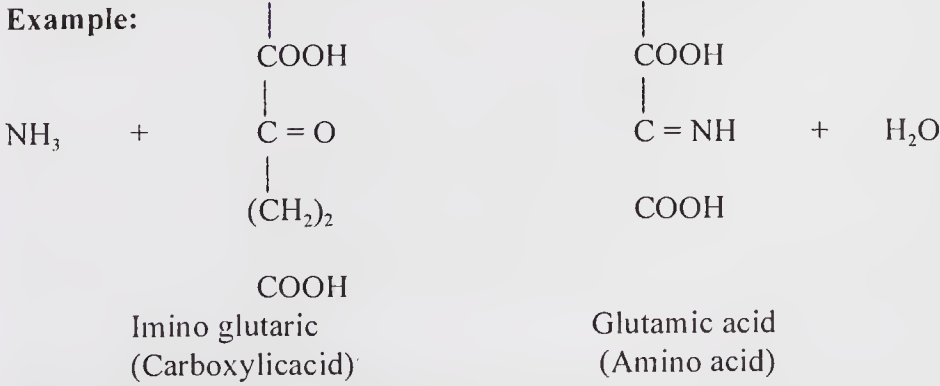


Ammonia combines with organic acids to form amino acids and ultimately proteins.



The site of nitrogen reduction is the enzyme nitrogenase, a two – protein complex consisting of a molybdenum and a iron containing member.

Example:



Amino acids combine together to form protein.

MICROBES AND SOIL FERTILITY

Effect of Soil, Water and Air on Micro-organisms

- Living component constitute less than 1% of total volume but play a key role in building up and maintenance of soil fertility. A-horizon mostly controls the beneficial or harmful effects of micro flora. However, microbial activity is controlled by other factors like moisture in soil. *i.e.* the soil remaining wet, reduces microbial activity. Water may remove nutrients in solution downward beyond the reach of micro-organisms. The portion of pore space not occupied by water is filled with gas. This contains more CO_2 , which also increases with soil depth. If a soil is well aerated the microbial processes requiring O_2 proceed at a rapid rate. Poor drainage and waterlogging cause improper aeration in soil, and rate of microbial transformations are reduced. Under such conditions, production of chemical e.g. CH_4 , H_2S , organic acid takes place, which are harmful to the plants. Accumulation of ferrous and manganous ion is also common especially under submerged paddy cultivation.
- All the nutrients contained in a soil are not readily available to plants or micro-organisms. They are slowly released from soil, which acts as a reservoir of nutrients. This includes both cations and anions. Important cations include Ca^{++} , Mg^{++} , K^+ , and NH_4^+ . Inorganic nutrients assimilated by micro-organisms as anions include bicarbonate(HCO_3^-), nitrate(NO_3^-), phosphate(HPO_4^{--} or H_2PO_4^-), sulfate (SO_4^{--}) and molybdate(HMoO_4^-).
- Humus formation is the result of synthetic and decomposing activities of soil micro-organisms. It leads to some loss of carbonaceous materials and addition of new microbial tissues. Micro-organism constitutes the living component of soil ecosystem alongwith non-living components like mineral matter. Fertility of soil, which determines production ultimately, rests upon these micro-organisms. In normal soils maximum microbial activity is seen in the upper 15cm of soil. However, in organic soils the distribution pattern may be different, microbial population being greater at deeper layers.

Importance of Soil Organisms in Soil Fertility

- Soil organisms are responsible for many of chemical transformations in soil. Transformation reactions are microbial in nature. Micro-organisms play a great role in building soil fertility and maintaining the nutrients in an available form. Mineralization of complex sources or immobilization of minerals is taking place through involvement of different micro-organisms. The value of bulky manure increases because of activity of microbes. The microorganisms, which utilize carbonaceous material for their energy, transform organic nitrogen, phosphorus and sulfur compounds into simple organic compounds, which are utilized by higher plants.
- Many mineral nutrients including micronutrients held in an unavailable organic combination are also released in an available form by microbial decomposition.
- Bacteria constitute the most abundant group of micro-organisms. (In soils, 10–100 million bacteria are present per g of soil). The bulks of soil bacteria

are heterotrophic and utilize readily available source of organic energy from sugar, starch, cellulose and protein.

- The number of actinomycetes may be as high as 200 million per g of soil and may increase in manured soils. Actinomycetes grow on complex substance such as keratin, chitin and other complex polysaccharides and thus they play an active role in humus formation.
- Soil fungi are mostly heterotrophs and use organic residues easily but their number vary in soil depending on whether a species has a dominant vegetative or reproductive phase in the soil environment.
- The activity of micro-organisms that decompose organic matter is responsible for other beneficial changes. For example, organic acids and carbon dioxide that are released by decomposition make insoluble phosphates and other unavailable compounds more available to plants. The organic materials added to soil are the products of photosynthesis by higher plants. Through photosynthesis, carbon in compounds is returned to the atmosphere as CO_2 by plant respiration. Roots and stubbles bring about 0.5 to 5 tonnes/ha/year. organic matter and with straw the total addition can be 1–10 tonnes/ha/year. Organisms derive energy for their growth, reproduction and carbon required for synthesis of cell components from the metabolism of organic compounds.
- The addition of sulfur to alkali soils is beneficial because of the activity of sulfur oxidizing bacteria, which produce sulfuric acid. The latter neutralizes the alkalinity. The addition of sulfur with bulky manure is particularly efficient.
- The role of nitrogen fixing organisms in the recuperation of nitrogen reserves in soil has been established. Both symbiotic and non-symbiotic organisms are responsible for maintaining the nitrogen economy in soils.
- The phosphate manuring in legumes, e.g. berseem clover and sunhemp, particularly on phosphate deficient soils, has helped to produce better crops with vigorous nitrogen fixation.
- Phosphate solubilizing bacteria helps in maintaining the available forms of phosphate because phosphobacterin is likely to succeed in areas where available phosphorus is low provided there is an adequate application of organic matter in soil.
- Organic matter encourages microbial activity and humus formation. The mycelial strands of fungi and actinomycetes the mucilaginous growth of the bacteria and the polysaccharides produced by them improve properties of organic matter.
- Wormcasts from earthworms is an important medium for multiplication of micro-organisms. Several organisms multiply in this medium, which is present, in most soils. It is generally believed that aggregating power of micro-organism is dependent on the organic matter content of the soil.
- The soil micro-organisms have intimate relationship with the root system and thus help plants to obtain nutrients from the soil. The efficiency of the plant in absorbing the nutrients from the soil is largely dependent on the associated micro-organisms.
- Micro-organisms present in air, water and soil when brought in contact with plant most favourably influence its plant growth. Sometimes they may be harmful.

- Upon the death of plant or animal, micro-organism cause decay of dead tissues forming microbial cells and a vast, heterogeneous body of carbon compounds.

Occurrence of Bacteria

- Bacteria in close association with soil include *Streptomyces*, *Nocardia*, *Erwinia*, *Thiobacillus*, *Rhizobium*, *Azotobacter*, *Nitrobacter*, *Nitrosomonas*.
- Cellulose occurs in seed bearing plants, algae and fungi. Strong cellulolytic fungi include *Aspergillus*, *Fusarium*, *Trichoderma*.

Some Common Soil Micro-organisms and their Functions

i)	Cellulose breakdown	Bacteria	-	<i>Angiococcus Polyangium</i>
	Utilise cellulose	Bacteria	-	<i>Pseudomonas Bacillus</i>
	Anaerobic decomposition of cellulose	Bacteria	-	<i>Clostridium</i>
ii)	Metabolize Hemicellulose (glycans, xylan, mannan, galactan)	Bacteria	-	<i>Bacillus Vibrio</i>
	” ” ”	Fungi	-	<i>Penicillium, Rhizopus Trichoderma, Cunninghamella</i>
iii)	Decomposition of Lignins (Most fungi that attack lignin also utilize cellulose)	Fungi	-	<i>Clavaria, Armillaria, Clitocybe, Marasmius, Pholita</i>
	Utilize lignin	Bacteria	-	<i>Arthrobacter, Flavobacterium, Pseudomonas, Micrococcus Xanthomonas</i>
iv)	Starch (hydrolyses starch)	Bacteria	-	<i>Bacillus, Clostridium, Micrococcus, Pseudomonas, Flavobacterium, Nocardia, Streptomyces</i>
	Starch (hydrolyses starch)	Fungi	-	<i>Aspergillus, Rhizopus, Fusarium</i>
v)	Pectic substances (hydrolyses pectic subst. Polysaccharides)	Bacteria	-	<i>Bacillus, Clostridium, Arthrobacter, Flavobacterium, Micrococcus, Pseudomonas</i>
	” ” ”	Fungi	-	<i>Aspergillus, Fusarium, Alternaria</i>
vi)	Can utilize inulin	Bacteria	-	<i>Pseudomonas, Flavobacterium, Micrococcus, Clostridium</i>
vii)	Can utilize chitin	Fungi	-	<i>Streptomyces, Nocardia</i>

PHOTOCHEMICAL REACTIONS

Photochemical processes are predominantly responsible for nitrogen transformation. The process is activated by addition of humic acid and zinc oxide.

Table 21.4. Status of microbial population and major available plant nutrients (mean values) during decomposition of organic substrates

Days after incorporation of organic substrates	Microbial population / g over dry soil				Available Nutrients	
	Rhizobium (x10 ⁴)	Azotobacter (x10 ³)	Fungal (x10 ³)	PSM (x10 ³)	N (mg kg ⁻¹)	P (mg kg ⁻¹)
PS + Soil (1:3)	81.33	127.54	127.5	133.56	64.14	14.86
SS + Soil (1:3)	92.22	169.32	138.93	152.95	85.35	15.52
GPW+ Soil (1:3)	50.03	113.73	92.78	107.95	91.26	15.84
PS + GB Soil (1:1:3)	78.75	171.02	122.23	133.51	71.61	15.09
PS + PM + Soil (1:1:3)	86.95	160.62	132.75	134.28	65.07	14.53
PS + Urea + Soil (1:1:3)	53.99	131.87	91.19	89.66	69.00	15.22
SS + GB + Soil (1:1:3)	101.27	178.03	145.86	157.44	127.73	16.54
SS + PM + Soil (1:1:3)	95.25	176.68	109.09	130.25	77.88	15.67
SS + Urea + Soil (1:3)	62.67	142.72	81.05	98.22	82.84	14.91
GPW + GB + Soil (1:1:3)	67.88	148.53	94.48	118.58	107.53	16.28
GPW + PM + Soil (1:1:3)	67.80	136.58	93.94	95.82	84.68	14.77
GPW + Urea + Soil (1:3)	47.62	113.81	79.63	81.99	81.16	14.38
Control (Soil only)	41.62	105.37	56.64	75.86	63.86	10.30
Check (Soil + Azotobacter)	47.42	128.00	61.06	82.20	64.07	11.53

Source: Patil et al 2000

PS, Paddystraw; SS, Soybean straw; GB, Green berseem; PM, Poultry manure; GPW, Green parthenium weed, Organic substrate : Air dry soil (in ratio of 1:3)

Organic materials like dung and straw not only increase plant nutrients to the extent they are contained in them but help to fix nitrogen during oxidation of carbonaceous residues.

Dhar (1961) has brought out the importance of photochemical nitrogen fixation. He has reported larger additions of nitrogen to soils in the presence of light than in the dark. The addition of wheat straw and molasses increased the nitrogen fixation, particularly when combined with phosphate application.

It has been observed that more nitrogen fixation occurs in light than in dark by incorporating straw with soil or sand and that calcium phosphate increased the amount of nitrogen fixation. Organic matter, zinc, bismuth and the mercury salts

Different stages of decomposition

Days after incorporation of organic substrates	Microbial population / g over dry soil				Available Nutrients	
	Rhizobium (x10 ⁴)	Azotobacter (x10 ³)	Fungal (x10 ³)	PSM (x10 ³)	N (mg kg ⁻¹)	P (mg kg ⁻¹)
15	76.87	180.31	122.08	114.82	102.91	11.87
30	68.65	147.95	103.35	104.08	101.01	11.03
45	67.39	135.54	87.46	106.53	80.01	12.03
60	68.31	122.35	97.65	116.27	70.29	14.94
90	67.36	130.57	109.97	126.97	51.59	22.62

Table 21.5. Nutrients composition of different organic substrates

Organic susbtrates	Org. (%)	N (%)	P (%)
Paddy straw	36.6	0.54	0.034
Green berseem	36.3	3.00	0.250
Soybean straw / Trash	48.3	1.38	0.038
Green parthenium weed	49.2	1.03	0.028
Poultry manure	—	2.87	0.088
Cattle dung	—	3.99	0.100

Source: Patil *et al.* 2000

posses striking catalytic power.

The fact that the nitrogen fixation occurs in the dark proves the role of biological nitrogen fixation. It is now known that certain photochemo-autotrophs like sulfur bacteria, rhodospirillum, and a blue green alga in waterlogged paddy soils is present in soil. These organisms are also responsible for nitrogen fixation that is expected to be accelerated due to the presence of light.

MICROBIAL POPULATION IN SOIL

Microbial population and availability of major plant nutrients is influenced by organic substrate decomposition. The extent of availability of plant nutrients depends not only on the type of substrates but also on the building up of micro-organisms. The studies conducted by Patel *et al.* (2000) show that microbial composition and extent of available plant nutrients are affected during

Table 21.6. Changes in microbial population expressed in CFU g⁻¹ dry compost during composting

	Bacteria × 10 ⁷	Actinomycates × 10 ⁶	Fungi × 10 ⁵	N ₂ Fixing bacteria × 10 ⁶	Phosphate solublizers × 10 ⁶	Thiosulphate oxidisers × 10 ⁴
Traditional compost	62	154	27	57	140	189
Vermi compost	92	234	59	89	185	386
Enriched compost	82	156	79	77	170	238
Enrichedvermi compost	121	213	53	81	177	365
Supcrenriched compost	82	201	94	64	169	323
Superenriched vermicompost	123	283	68	128	211	292

Source: Mukherjec *et al.* 2000

decomposition (Table 21.4). Organic substrates are rich in organic phosphates and are rendered available by soil micro-organisms particularly PSM through secretion of organic acids. These micro-organisms are composed of nucleic acids, phospholipids and phytin. Nutrient composition of different substances is given in Table 21.5.

Microbial changes take place during the process of composting (Table 21.6). The addition of N, P or inoculation of cellulolytic fungi hastens the process of decomposition. Non-symbiotic nitrogen fixing bacteria and phosphate solubilizing fungi often improve the nutritional status of compost. Pyrite reduces the volatilisation loss of nitrogen during the process of composting. Earthworms feed on organic wastes and then excrete the mucus coated undigested matter as wormcasts. Wormcasts are rich sources of organic and inorganic nutrients and consequently of microbial activity.

Enriched and superenriched compost registered higher nitrogen fixing, phosphate solubilizing and thiosulphate oxidising power than that of traditional compost. Superenriched compost was superior to enriched compost in relation to the nitrogen fixing power. Earthworm brought about a marked stimulating influence on nitrogen fixing, phosphate solubilizing and thiosulphate oxidising power in their respective composted series. That might be due to the high proliferation of the concerned micro-organisms in those vermicomposted series. (Mukherjee *et al* 2000).

References and Suggested Readings

- Alexander, M. (1977). *Introduction to Soil Microbiology*, 2nd edn. John Wiley and Sons, Inc., New York and London.
- Bisby, G.R. (1953). *An Introduction to the Taxonomy and Nomenclature of Fungi*. The Commonwealth Mycological Institute, Kew, Surrey (UK).
- Bold, H.C. and Wynne, M.J. (1978). *Introduction to the Algae*. Prentice-Hall of India, New Delhi.
- Dhar, N.P. (1961). Nitrogen problem. Presidential Address to the 48th Indian Science Congress, Roorkee, 1961.
- Lavelle, P., Dangerfield, M., Fragosa, C. Eshenbrenner, V. Lopez – Hernandez, D. Pashansi, B. and Brussard, L. (1994). The relationship between soil macrofauna and tropical soil fertility. In : *The Biological Management of Tropical Soil Fertility* Woomer, PL and Swift M.L.). J Wiley and Sons, Chichester, UK.
- Mukherjee, D., Das, S., Saha, N., Sahu, S.S. Chakravarty, A., Halder, M. Bhattacharaya, K. and Mukhopadhyay, N. 2000. *International Conference on Managing Natural Resources for Sustainable Agricultural Production in the 21st Century*, Vol. 2, New Delhi.
- Patil, V. Rawat, A.K. and Verma, L.N. 2000. Vol.2 : Natural Resources, pp. 704–6. *International Conference on Managing Natural Resources for Sustainable Agricultural Production in the 21st Century*, New Delhi, Feb. 14–18, 2000.
- Pelczar, M.J., Jr., Georgi, C.E. and Lindegren, L.F. (1952). *Laboratory Manual for General Bacteriology*. John Wiley and Sons, New York.
- Purohit, S.S. (1994-95). *Microbiology – Fundamentals and Applications*. Agro. Botanical Publishers (India). New Delhi.
- Rangaswami, G. and Bagyaraj, I.J. (1993). *Agricultural Microbiology*. Prentice Hall of India Private Ltd., New Delhi.
- Rovira, A.D. (1965). Interactions between plant roots and soil micro-organisms. *Annual*

Review of Microbiology 19 : 241–66.

Singh, R.N. (1961). Role of Blue-Green Algae in Nitrogen Economy of Indian Agriculture. Indian Council of Agricultural Research, New Delhi.

Starr, M.P., Stolp, H. Truper, H.G., Balows, A. & Schlegel, H.G. (1981). *The Prokaryotes – A Handbook on Habitats, Isolation, and Identification of Bacteria*. 2 vols. Springer-Verlag, New York.

Stephenson, J. (1930). *The Oligochaete*. Oxford University Press.

Subba Rao, N.S Ed. (1979). *Recent Advances in Biological Nitrogen Fixation*. Oxford and IBH Publishing Co., New Delhi.

Subba Rao, N.S. (1977). *Soil Micro-organisms and Plant Growth*. Oxford and IBH Publishing Co., New Delhi.

Subba Rao, N.S. (1995). *Soil Organisms and Plant Growth*. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi.

Virtanen, A.I. (1947). *Biological Review* 22 : 239.

Waksman, S.A. (1961). *The Actinomycetes*, Vol. 11: Classification, Identification and Descriptions of Genera and Species. Williams and Wilkins Co., Baltimore.

Wilson, P.W. and Burris, R.H. (1953). Biological nitrogen fixation. A reappraisal. *Annual Review of Microbiology* 7: 415–32.

QUESTIONS

Q. 1. Fill in the blanks

- i) Those micro organisms which grow at temperature below 10°C are known as _____.
- ii) _____ equal one half of the microbial biomass in the soil.
- iii) Bacteria capable of developing both in the presence and absence of oxygen are called _____.
- iv) _____ colonies show powdery consistency and stick firmly to agar surface.
- v) Fungi _____ attack lignin, cellulose and related compounds.
- vi) _____ fungi are found in forests and grasslands where there are ample moisture and organic residues.
- vii) Nematodes, which can infest on the roots of plant species are called _____.
- viii) _____ method helps in the isolation of iron and sulfur oxidizing micro organisms and those that utilize nitrate.
- ix) Direct sunlight is injurious to most of the micro organisms except _____.
- x) Addition of nitrates inhibits the activity of free living nitrogen fixing bacteria like _____.
- xi) _____ means two micro organisms behave entirely independently.
- xii) _____ families of bacteria constitute the majority of heterotrophic free living nitrogen fixing bacteria .
- xiii) Bacteria belonging to the genus _____ live freely in soil and in the root region of both leguminous and non- leguminous plants.
- xiv) The overall effect of the process of biological nitrogen fixation is to reduce nitrogen gas to _____.
- xv) The site of nitrogen reduction is the enzyme _____.

Answers

(i) psychrophiles (ii) bacteria (iii) facultative anaerobic (iv) actinomycetes (v) basidiomycetes (vi) mushroom (vii) heterodera (viii) enrichment cultures (ix) algae (x) azotobactor (xi) neutralism (xii) azotobacteraceae (xiii) rhizobium (xiv) ammonia (xv) nitrogenase.

Q. 2. Choose the correct answer

- i) Micro-organisms which can proliferate in higher than 45° C temperature are thermophiles/ mesophiles.
- ii) Photoautotrophs/ chemoautotrophs derive their energy from sunlight.
- iii) Actinomycete / Bacteria colonies appear slowly.
- iv) Fungi/ actinomycetes are strictly aerobic.
- v) Diatoms is a type of algae/ fungi.
- vi) Algae have an association with fungi/ actinomycetes.
- vii) Molds, yeast and mushrooms are grouped as fungi/ algae.
- viii) Buried slide/soil plate method is useful to study quantitative changes in soil microflora under the influence of soil amendments.
- ix) Actinomycetes/ bacteria prefer dry conditions.
- x) Micro organisms are less/ more active at the wilting of plants.
- xi) Mutualism/ commensalism implies obligatory dependence of organisms.
- xii) Azotobactor is a non symbiotic/ symbiotic nitrogen fixing bacteria.
- xiii) In general, the rate of microbial transformations are reduced/ increased under water logging conditions.
- xiv) In organic soils , microbial activity is greater at deeper layers /surface.

Answers

(i) thermophiles (ii) photoautotrophs (iii) actinomycetes (iv) fungi (v) algae (vi) fungi (vii) fungi (viii) buried slide (ix) actinomycetes (x) less (xi) mutualism (xii) non symbiotic (xiii) reduced (xiv) deeper layers

Q. 3. Define the following

(i) Community (ii) Ecosystem (iii) Synergism and competition (iv) Antibiotic (v) Rhizosphere (vi) R:S ratio (vii) Phylloplane (viii) phyllosphere (ix) Phytoalexin (x) Mycorrhiza (xi) Bacterization.

Q. 4. Differentiate between

(i) Soil flora and Soil fauna (ii) Heterotrophs and Autotrophs (iii) Autochthonous and Zymogenous organisms (iv) Molds and Yeast (v) Nematodes and Rotifers (vi) Non symbiotic and Symbiotic nitrogen fixation.

Q5 Write short notes on

(i) Bacterial population in soil (ii) Soil respiration and soil enzymes methods of studying soil organisms (iii) Effect of cultural factors on soil organisms (iv) Commensalism (v) Rhizosphere effect (vi) Organisms on phyllosphere (vii) Elicitors (viii) Vascular arbuscular (VA) Mycorrhiza (ix) Use of soil fungiasts (x) Mechanism of nitrogen fixation (xi) Photochemical reactions.

Q. 6. Comment on the following statements

- i) Fungi are dominant in acid soils.
- ii) Some fungi help in mobilization of soil phosphorus and nitrogen into plants.
- iii) The algae tend to be concentrated near the soil surface.
- iv) Alga cells create favorable conditions for colonization by higher plants.
- v) Application of organic manure increases the number of soil protozoans.
- vi) The role of earthworms has assumed greater relevance as a supercomposter by mixing materials.
- vii) Earthworms increase soil fertility.
- viii) Soil pH influences the soil enzymes and plays an important role in microbial activity.
- ix) Well-aerated soil rich in organic matter is an essential prerequisite for maximum number and activity of heterotrophic micro organisms.
- x) Different group of micro-organisms exist in soil, in a dynamic equilibrium.
- xi) In a given location, the interactions between soil, plant and micro organisms become distinct and dynamic.
- xii) There is an intricate relationship between the plant root and soil system which functions in a dynamic equilibrium in a given location and biosphere.
- xiii) Root exudates provide food base for the growth of antagonists. Give examples.
- xiv) Virus infected plants which results in stunting could be restored to normalcy by spraying the leaves with thiourasil or gibberellins.
- xv) Algae and fungi live in intimate symbiotic relationship.
- xvi) Azotobactor improves the rhizosphere micro flora.
- xvii) Poor drainage and waterlogging conditions are harmful to the plants .
- xviii) Fertility of soil rests upon micro organisms.
- xix) Actinomycetes play an active role in humus formation.
- xx) Microbial changes take place during the process of composting.

Q. 7. Answer the following in brief

- i) Enlist important microbial population in fertile soil.
- ii) What are obligate chemoautotrophs. Give examples.
- iii) What is the role of bacteria in soil.
- iv) Name five genera of fungi which are commonly found in soils and can be isolated by conventional methods.
- v) What is the role of saprophytic fungi.
- vi) Enlist the favorable effects of algae on plant growth.
- vii) Enlist common types of earthworm found in India.
- viii) What are the favorable conditions that enhance earthworm population in soil.
- ix) What are the causes that adversely affect earthworm's population.
- x) Enlist a few micro organisms that excrete antibiotic substances.
- xi) Enlist factors influencing rhizosphere effect .
- xii) What is the significance of root exudates in rhizosphere.

- xiii) Enlist a few micro-organisms responsible for breakdown of cellulose, decomposition of lignin, hydrolysis of starch and pectic substances and can utilize inulin and chitin in soil during decomposition of organic matter.
- xiv) Give a brief account of microbial population with organic substrates.

Q. 8. Answer the following in detail

- i) Explain the role of soil organisms in soil plant animal ecosystem.
- ii) Classify soil organisms .
- iii) Describe the role of earthworms in soil.
- iv) Enlist different methods of studying soil organisms and their activities.
- v) What are the possible interactions between two species as given by Campbell (1983).
- vi) Give an account of practices to be followed in the management of rhizosphere.
- vii) Explain the importance of soil organisms in maintaining soil fertility.



Soil Organic Matter

Soil organic matter consists of decomposing plant and animal residues, or any substance of organic origin either living or dead. Organic matter is responsible for the maintenance of physical condition of the soil for successful crop production namely structure, tilth, aeration, water holding capacity, resistance to erosion etc. Soil organic matter may be distinguished from humus.

- Humus is a highly complex, organic, fairly colloidal, stable and amorphous, brown to black material which is formed as a result of decomposition of plant and animal residues by micro-organism, with no trace of the structure of the material from which it is derived. The percentage composition of well digested humus is approximately: carbon (55 to 60%), hydrogen (4 to 5%) oxygen 35–40%, nitrogen (5–6%) plus a variable amount of mineral matter containing sulphur, phosphorus, iron, calcium, magnesium, potassium etc. The nitrogen carbon ratio of such material is approximately 1:10. The ratio remains more or less constant whatever the nature of raw organic matter at the start.
- Humus is more complex than original organic matter. Synthesis of organic substance is involved in humus formation. Bacteria, actinomycetes and fungi are involved in the decomposition of organic matter. These micro-organisms produce different soil enzymes, which are responsible for the decomposition of organic matter. As new organic matter is formed, a part of the old becomes mineralized. Thus organic matter is a dynamic material in soil.

The soil develops its typical profile characteristics only when it is intimately associated with decaying organic matter. If the humus lies just above the mineral horizon it is called mor. If the organic matter has been intimately mixed with mineral matter and decomposed, this humus incorporated mineral layer is called mull.

COMPOSITION AND SOURCES

Sources: Plant tissue is the main source of soil organic matter. Leaves and roots of trees, shrubs, grasses and other plants etc. annually supply large quantities of organic residues. Organic materials are decomposed and digested by soil organisms and then become part of the underlying soil by infiltration or by actual physical cooperation. These plant residues form the primary material for the food of the soil organisms. The quantities of underground plant parts vary with different crops. In top 15 cm of the soil the dry matter in root parts from a crop of pea is about 200 kg, of wheat 500–600 kg and of grasses 5000 to 8000 kg/ha. Animals usually are considered secondary sources of organic matter. As they attack the original plant tissues, they contribute waste products and leave their own bodies

after death. Certain forms of animal life, especially the earthworms, termites and ants also play an important role in the translocation of soil and plant residues.

Composition of organic residues: Nearly 75% moisture is present in plant residues. The remaining 25% of the dry matter is made up of carbon (10 to 12%) oxygen (9 to 10%), hydrogen (1.5 to 2.5%), nitrogen (1–2%) and mineral matter (1-3%). Although other elements are present in small quantities but they play a vital role in plant nutrition and in meeting micro-organism body requirements.

Composition of a plant: In general, native plant tissue is made up of :

Contents		Per cent
Carbohydrates	Celluloses	20 to 50
	Hemicelluloses	10 to 30
	Starches, sugar etc	1 to 5
Proteins		1 to 15
Fats, waxes, tannins etc		1 to 10
Lignins		10 to 30

In early stage of growth, plants are rich in starch and proteins. With maturity, the percentage of cellulose and lignin increase.

Composition in organic residues: Soil organic matter is a very complex

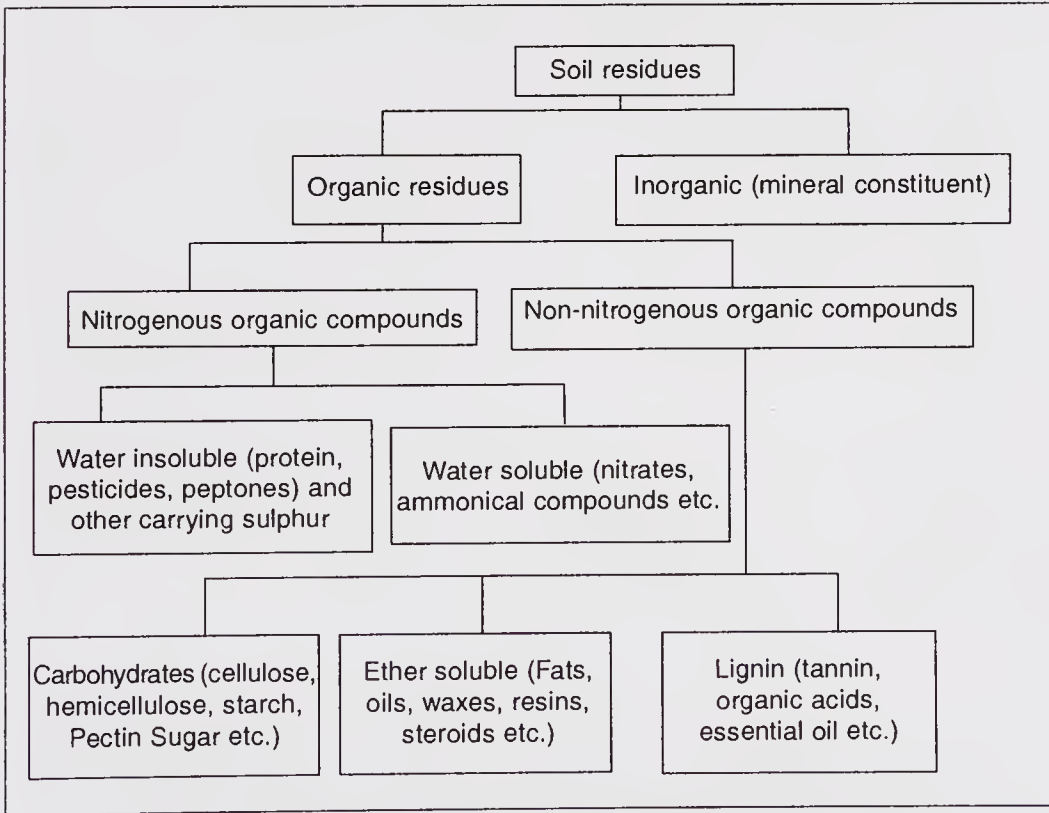


Fig. 22.1. Chart showing different compounds in organic residues

substance. Organic residues consist of both organic and inorganic fractions (mineral constituent or ash). A simple outline for the presence of different compounds in organic residues is given in (Fig 22.1).

The composition varies according to types of plant tissues. However, the most tentative composition has been shown in the above scheme. Lignins containing carbon, hydrogen and oxygen are very resistant to microbial decomposition. The crude proteins are the most complicated compounds and contain C, H, O, N, S, Fe, and P.

DETERMINATION OF SOIL ORGANIC MATTER

Due to importance of organic matter, its determination is made as a routine procedure. However, there is no accurate method available because of the complex nature of organic matter.

- (a) There are two methods for direct determination of organic matter, loss on ignition, and oxidation with hydrogen peroxide. The known quantity of the soil is ignited and loss in weight is determined. The loss in weight includes hygroscopic moisture, carbon dioxide from calcium carbonate, and CO_2 from elemental carbon present as charcoal. Thus the results are large and loss in weight in above determination is usually referred to as loss on ignition.
- (b) In another method, the organic matter is destroyed by hydrogen peroxide. This method can be used in soils which do not contain high MnO_2 , and < 1 per cent CaCO_3 . Generally low values of results (the values obtained are less in comparison to other methods) are obtained by this method.
- To overcome these difficulties, a better estimation of organic matter is obtained by determining organic carbon. By multiplying organic carbon to a factor 1.724, organic matter is calculated. The most accurate method is the dry combustion procedure, in which, a known quantity of soil (previously treated with H_2SO_4 to destroy CaCO_3) is ignited. The CO_2 evolved is absorbed in soda-lime tube. Thus the increase in weight is due to CO_2 from organic matter. The amounts of organic carbon and organic matter are calculated. This method is good but time consuming and equipment is also expensive.
- A quicker and easier method is to affect the oxidation of organic matter by chromic acid. A known quantity of soil is treated with standard $\text{K}_2\text{Cr}_2\text{O}_7$ solution in the presence of concentrated sulfuric acid. The excess of $\text{K}_2\text{Cr}_2\text{O}_7$ is determined by titrating against standard FeSO_4 solution. This procedure is known as Walkley and Black method. This has been adopted as a routine procedure for its determination. $\text{C} \times 1.724$ or $\text{Total N} \times 20$ gives an approximate estimate of the humus content of soils. In using the factor $\text{Total N} \times 20$ it is assumed that practically all the nitrogen of soil is in the humus.

CARBON CYCLE

Carbon is a common constituent of all organic matter (plant and animal residues) and is involved essentially in all life processes. The transformations of carbon in different forms, is termed carbon cycle (Fig. 22.2).

Mineralization and Immobilization

The decomposition of plant and animal remains in soil constitutes a basic biological process in that carbon is recycled to the atmosphere as CO₂ and nitrogen (N) is made available as NH₄⁺ and NO₃⁻. In the process, part of the nutrient element (C) is assimilated by micro-organisms and incorporated into microbial tissues. The conversion of organic forms of C, N, P and S to inorganic or mineral forms is called ‘mineralization’ and the conversion of inorganic forms of C, N, P and S to their organic forms is known as ‘immobilization’.

Carbon cycle: an all Inclusive Process

The carbon cycle revolves around CO₂, its fixation and regeneration. Through the process of photosynthesis, higher plants as their sole carbon source assimilate CO₂. Microbial metabolism assumes the dominant role in the cyclic sequence on the dead plant and animal tissues. The dead tissues are transformed into microbial cells. The carbon cycle is all-inclusive because it involves the soil and its teeming fauna, flora and higher plants but also all animal life including human being. The carbon cycle is shown below.

Carbon : Nitrogen Ratio

When fresh plant residues are added to the soil, they are rich in carbon and poor in nitrogen. This results in wide carbon nitrogen ratio (say 40:1). Upon decomposition, the organic matter of soils changes to humus and have a narrow C:N ratio (say 10:1). For example, wheat straw, when added to the soil, increase the soil microbial proportion and a large amount of CO₂ would be released. In this process, all of the mineral nitrogen is immobilized by it being used up for

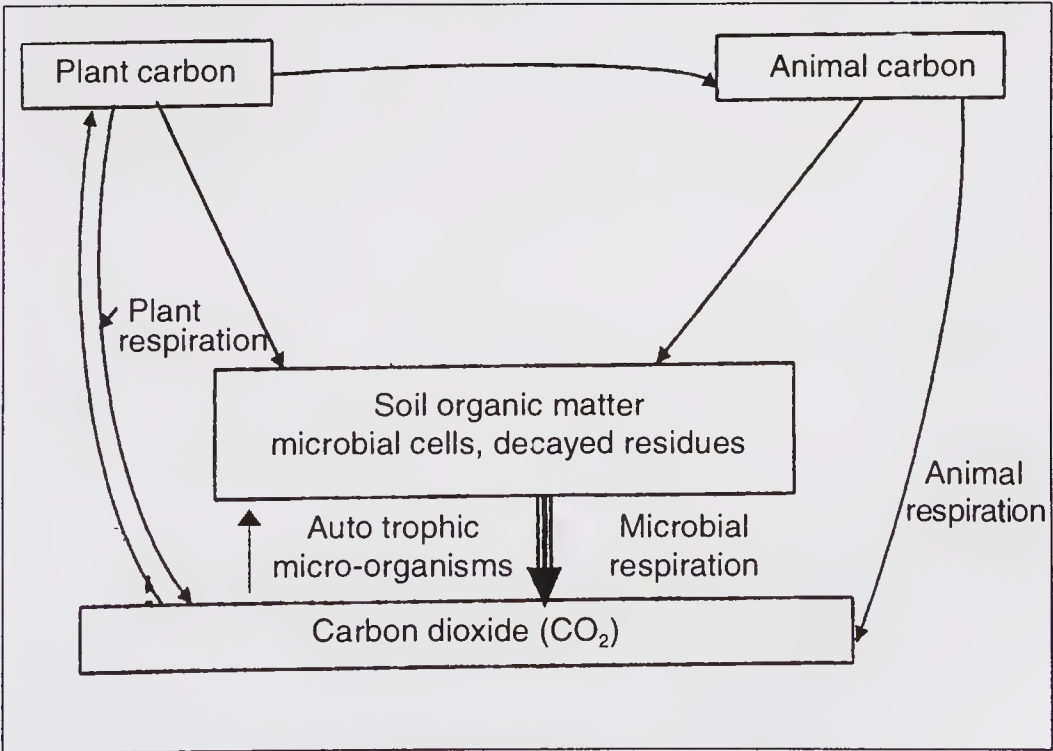


Fig. 22.2. Carbon Cycle

synthesis of body protein by micro-organisms. When the decomposition of fresh organic residues has proceeded to the extent when the C:N ratio is reduced to 20:1 or so, available nitrogen in soils tends to increase. Low ratios of carbon to nitrogen (10:1 or smaller) in soil organic matter generally indicates an advance stage of decomposition and resistance to further microbiological decomposition. A wide ratio of C : N (40:1 or more) indicates little decomposition , susceptibility to further and rapid decomposition.

In view of this it is desirable to mix highly carbonaceous material, like straw with a small quantity of ammonium sulfate. With this available source of nitrogen from ammonium sulfate, the decomposition of fresh organic material is hastened and the release of available nitrogen is affected in a shorter period of time.

HUMUS-BIOCHEMISTRY AND THEORY OF HUMUS FORMATION

Humus Formation

The formation of humus is a bio-chemical process. Humus may be defined as a complex and rather resistant mixture of brown or dark brown amorphous and colloidal substances modified from the original tissues or synthesized by various soil organisms. The bulk of these compounds have resulted from two general

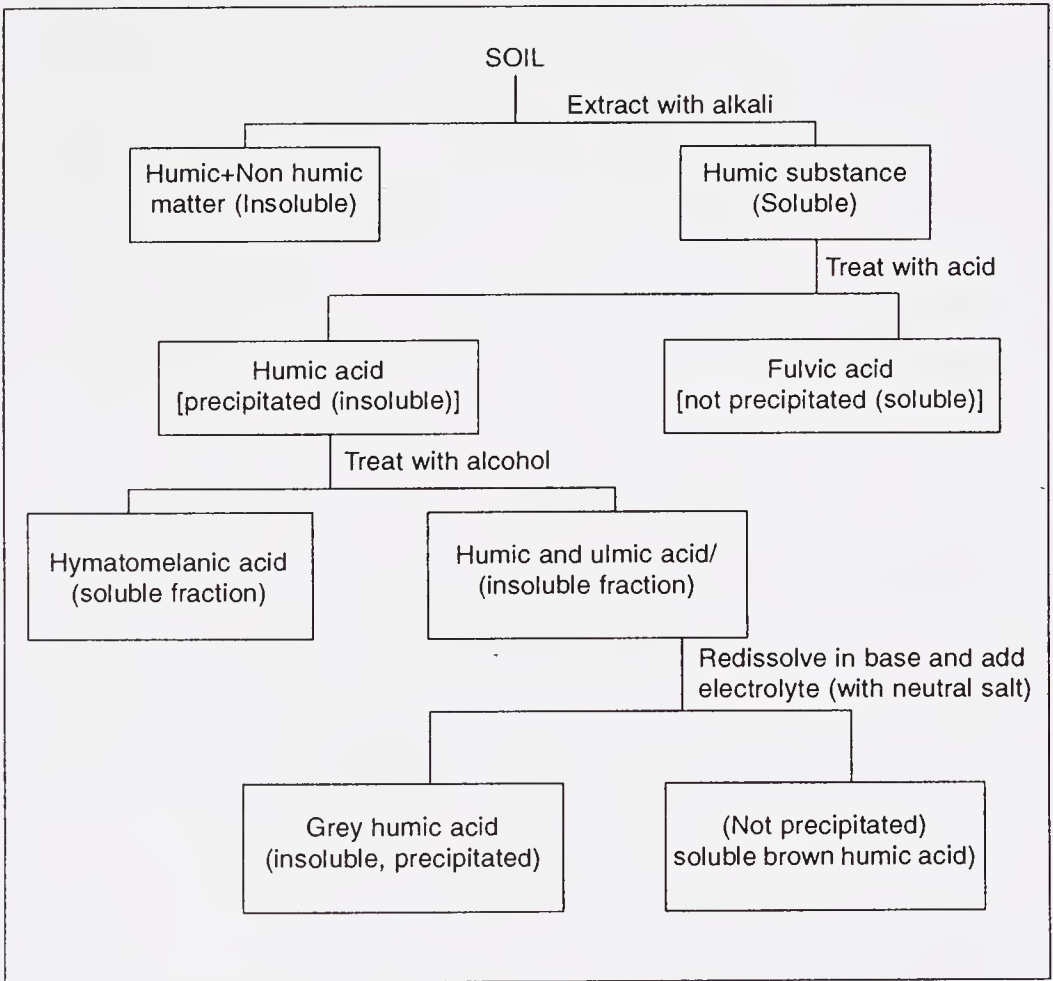


Fig. 22.3. Fractionation scheme of soil organic matter

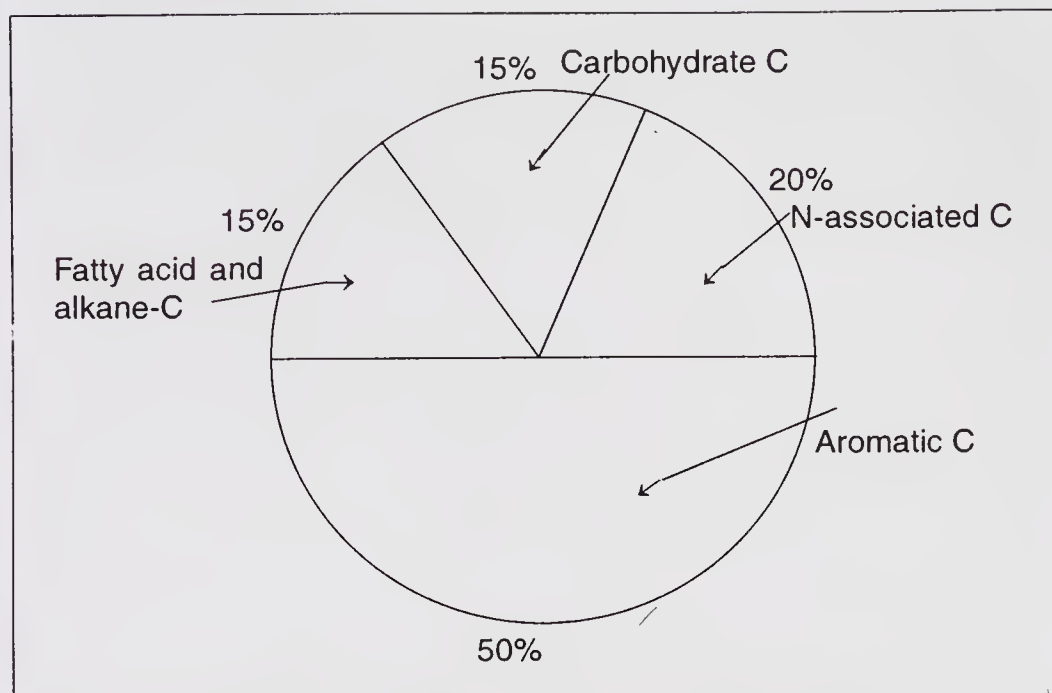


Fig. 22.4. The approximate composition of carbon in soil humus

types of biochemical reactions, decomposition and synthesis. Decomposition implies transformation to simpler compounds. Besides decomposition of organic matter, synthesis of organic substances is involved in humus formation.

Decomposition occurs as chemicals in the plant residues are broken down or drastically modified by soil organisms. Humification of organic residues incorporated in the soil depends upon their chemical composition and soil conditions influencing the activity of soil micro-organisms. In soil, organic residues of plant and animal origin undergo diverse changes.

Humus - The Humic and Non Humic Groups

There are two general groups of compounds that collectively make up humus, the humic group and non humic group.

Humic group: The humic substances make up about 60-80 % of the soil organic matter. They are comprised of the most complex materials, which are also the most resistant to microbial attack. Humic substances are characterized by aromatic, ring type structures that include polyphenols and polyquinones which are formed by decomposition, synthesis and polymerization.

On the basis of resistance to degradation and of solubility in acids and alkalis, humic substances have been classified into three chemical groups: a). fulvic acid, lowest in molecular weight and light in colour, soluble in both acid and alkali and most susceptible to microbial attack, b). humic acid, medium in molecular weight and colour, soluble in alkali but insoluble in acid and intermediate in resistance to degradation; c). humin, highest in molecular weight, darkest in colour, insoluble in both acid and alkali and most resistant to microbial attack. A simple fractionation scheme for humus or soil organic matter is shown in Fig. 22.3.

Non humic group: The non-humic group comprises of about 20–30 % of the

organic matter in soils. Non humic substances are less complex and less resistant to microbial attack as compared to humic substances. The non-humic substances are polysaccharides; polymers having sugar like structures and also polyuronides.

Humin: The structure of humin is similar to that of humic acid, but it contains less nitrogen. Humin matter is insoluble since it is tightly bonded around mineral impurities. Removal of these inorganic impurities involves drastic treatment of the fraction with hydrofluoric acid.

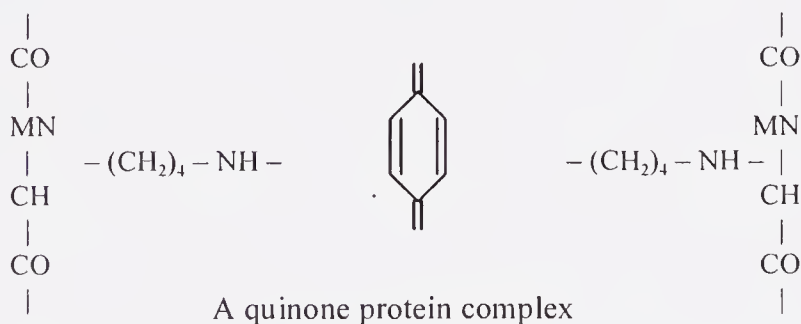
Theories of Humus Formation

Humic and fulvic acids are formed by the decomposition of plant component, metabolism process, repeated recycling of biomass C and polymerization. The approximate composition of carbon in soil humus is given in Fig 22.4. It is believed that polyphenols derived from plants are enzymatically converted to quinones which undergo self condensation or combine with amino compounds to form N containing polymers. Different theories have been advanced to explain the formation of humus.

Lignin theory: Waksman (1936) proposed these humic substances simply result from the incomplete degradation of lignin. This view was disproved when it was found that humic substances could be synthesised by fungi in the absence of lignin.

Kononova's concept: (i) Humic acid substances are formed by cellulose decomposing myxobacteria before lignin has begun to decompose. (ii) Humic acids are formed at the time of intense cellulose decomposition by the interaction of organic nitrogen compounds in myxobacterial protoplasm with soluble polyphenols. The reaction is catalyzed by oxidative enzyme of myxobacteria. (iii) Humic acid is formed by a mechanism involving condensation or polymerisation of a quinoid metabolic product of micro-organisms under slightly alkaline conditions.

Polyphenol theory: This theory was proposed by Flaig and Sochtig (1964). The humic molecules are the result of condensation of phenolic material. It involves the degradation and demethylation of lignin polyphenol monomers. These polyphenols are oxidised to quinones and condensed with low molecular mass



microbial products to form humic molecules. The low molecular mass microbial products are mainly amino acids, nucleic acids and phospholipids. The humic components tend to make up the largest proportion of soil organic matter; Humic molecules are often bound to other solid components of the soil matrix. Clay-humate complexes are formed when humates are adsorbed to clay minerals by polyvalent cations such as Ca^{2+} and Fe^{3+} , or by association with hydrous oxides,

either through coordination (i.e. ligand exchange) or through anion exchange (via positive sites, which exist on iron and aluminium oxides). Up to 10% of organic region carbon in soils is in the form of polysaccharides. Amino acid residues are also protected by phenolics through complex formations as below.

CHARACTERIZATION OF HUMUS

Procedures for Characterization of Organic Matter

Current procedures used in characterization of soil organic matter are based on the extraction of soil with alkaline solutions, particularly sodium hydroxide. Sodium hydroxide is thought to extract about 80% of the soil's total organic matter. Fig 22.3 illustrates the fractionation scheme of soil organic matter. Mild acid treatment (0.1M HCl) improves the subsequent yield of alkali-soluble material. Acid pre-treatment yields some soluble fulvic acid material. The characteristics of humus are contributed by the:

Humic acid : It consists of carbon (50 %), oxygen (40 %), hydrogen (5 %), nitrogen (3 %), phosphorus and sulfur (<1%).

Fulvic acid: It contains less carbon and more nitrogen and oxygen than humic acid. It has smaller proportion of aromatic units and greater aliphatic chains with carboxyl functional groups than humic acid fraction.

Humin: It is alkali insoluble fraction of soil humus.

Four major paths for the production of humus are illustrated in Fig. 22.5

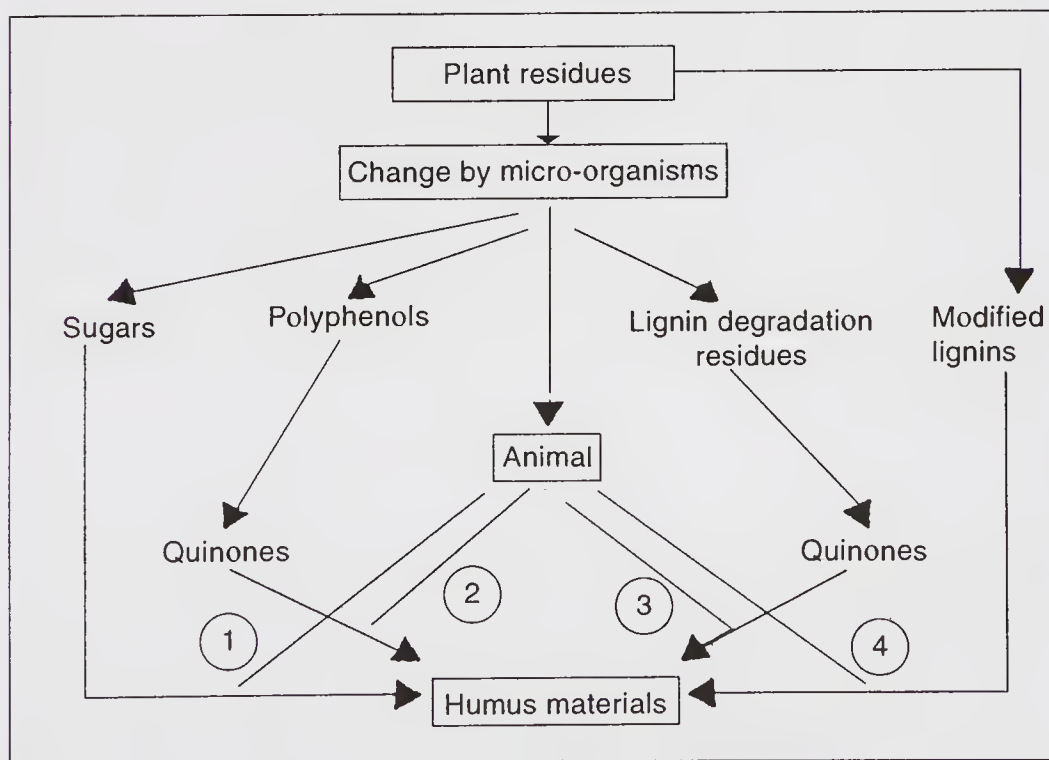


Fig. 22.5. Four major paths for the production of humus

Characterization of Humus

The characteristics of humus may be summarized as below:

- Humus is highly colloidal and amorphous in nature. Being colloidal it has a high adsorption capacity. It possesses low plasticity and cohesion.
- Humus colloids are composed basically of carbon, hydrogen and oxygen in the form of polyphenols, polyquinones, polyuronides and polysaccharides.
- The colloidal surfaces of humus are negatively charged. The negative charges arise from the exposed functional groups such as hydroxyl(-OH), carboxylic (-COOH), or phenolic ( OH) groups. The extent of negative charge is pH-dependent. Being negatively charged, humus micelle adsorb elements like Ca^{2+} , Mg^{2+} , H^+ , K^+ , Na^+ etc.
- At high pH value, the CEC of humus ranges from 150–300 cmol/kg.
- Humic acids are weakly dissociated and determine the buffering capacity of soil.
- Humic acids have a complex structure. It has mainly two types of structural units, i.e., phenolic and nitrogen containing compounds.
- Humus is acidic and hence is capable of reacting with soil minerals and extracting their bases.
- Humus acts like a sponge and is capable of absorbing 5 to 6 times its own weight of water. Upon absorption, it swells greatly and shrinks on drying. Humus tends to surround soil particles and acts as a glue. The organic coating facilitates the coagulation of clay by electrolytes. The large swelling capacity of humus and its cementing action enables humus to bring about a higher degree of aggregation in soils and more important, give stability to the aggregates.

Humus and Nutrient Availability

Humus enhances mineral breakdown. Nutrient availability may increase in two ways. First, H-humus act as an acid and can react with soil minerals as follows:



Microcline

Humic acid

Acid silicate Adsorbed K

The potassium is changed from a molecular to an adsorbed state, which is more readily available to higher plants. The second mechanism for increasing the availability of some cations is through the formation of organomineral complexes with these ions.

SOIL ENZYMES

An enzyme is a substance that is able to lower the activation energy of selected other compounds enough to allow the breaking of a particular bond under a particular environment. Such enzyme-influenced reactions are called biological reactions. The enzyme makes splitting the bond easier, but the process does not consume or destroy the enzyme. When one reaction is completed, the changed molecule diffuses into the solution and the enzyme then can split another similar bond. An activator that is not consumed or changed by such a process is called catalyst.

Plants, animals and micro-organisms produce enzymes. Free enzymes in the

soil have several fates. (i) They may function for a while before they themselves are decomposed by other enzymes and undergo further chemical breakdown. (ii) They may be denatured or inactivated permanently. (iii) Enzymes may become inactive because some reaction blocks access of the active parts of the enzyme to the substrate.

When enzymes have been experimentally added to soils, they have existed free and active only for a short time. Enzymes are produced by the decomposer and are directly responsible for the decomposition. Enzymes reduce the activation energy necessary to break the bonds of the organic materials. Different enzymes are needed for decomposition of a variety of organic substances.

There is a different enzyme for breaking each kind of bond. A list of common enzymes with their particular reactions is given in Table 22.1.

ROLE OF SOIL ORGANIC MATTER

Importance of Soil Organic Matter

The importance of soil organic matter in relation to soil fertility and physical conditions is widely recognized. Organic matter contributes its positive effects

Table 22.1. Common enzymes and their particular reactions.

Enzymes	Reactions involed
Urease	Break down urea $\left\{ \begin{array}{l} \text{H}_2\text{N} \diagdown \\ \text{H}_2\text{N}-\text{C} \end{array} \right. = \text{OO to water, CO}_2 \text{ and NH}_4^+$ It requires the presence of Ni ²⁺ ion.
Cellulase	Breaks celluloses, which are long chain of sugar units. Important in organic matter decay.
Protease	By involving water, it breaks the bond linking two amino acids $\begin{array}{ccc} \text{O} & & \text{OO} & \text{O} \\ \parallel & & \parallel & \parallel \\ [\text{R}_1-(\text{NH})-\text{C}-\text{R}_2] & \text{to form separate acids } [\text{R}_1-\text{NH}_2 \text{ and } \text{HO}-\text{C}-\text{R}_2] \text{ or parts of protein.} \end{array}$
Ligninase	Degrades lignin compounds of decomposed organic residues
Hemi cellulase	Breaks hemicellulose compounds of organic materials
Phosphatase	$\begin{array}{ccc} \text{O} & \text{---} & \text{O} \\ & \parallel & \\ & \text{II} & \end{array}$ By involving water, it breaks “humus –O-P-OH ₂ ” bond to produce “humus-OH” and H ₃ PO ₄ , which helps to decompose humus, making phosphorus available to plants.
Sulphatase	$\begin{array}{ccc} \text{O} & \text{---} & \text{O} \\ & \parallel & \\ & \text{II} & \end{array}$ By involving water, it breaks “humus -O-S-(OH) ₂ ” bond to $\begin{array}{ccc} \text{O} & & \text{O} \\ & \parallel & \\ & \text{II} & \end{array}$ produce “humus-OH ⁺ and H ₂ SO ₄ , making sulfur available to plants.
Proto pectinase	Decompose protopectin to form soluble pectin
Polygalac-turonase (PG)	Breaks linkages between galacturonic acid and pectin compounds to form free galacturonic acid.

on the chemical, physical and biological properties of the soil. Soil organic matter is the source of plant nutrients that are liberated in available forms during mineralization. Humic compounds also participate in soil formation and play an important role, especially in translocation or mobilization of clays, aluminium and iron giving rise to the development of spodic and argillic horizons. The role of soil organic matter is varied and extensive. It is summarized as follows:

Source of Plant Nutrients

- Organic matter is the source of 90–95% of the nitrogen in unfertilized soils. Organic matter can be the major source of both available phosphorus and available sulfur.
- Organic matter supplies some micronutrients like Fe, Mn, Cu and Zn to the soil and thereby increase nutrient content as well as improve soil fertility.

Favorably Influences Physical Properties of Soil

- Organic matter influences the soil color. Due to presence of adequate amount of organic matter, the color becomes brown to dark brown or black.
- Organic matter play a role in soil aggregation, thereby soil maintains favorable condition of aeration and permeability. Organic matter supplies polysaccharides, which are vital for improvement of soil structure.
- In presence of organic matter, the rate of infiltration and percolation of water is enhanced. Organic matter improves the drainage condition of soils. Organic matter reduces plasticity, cohesion, stickiness etc. in soils containing appreciable amounts of clay.
- Water holding capacity is increased by application of organic matter. Available water content in sandy soils increases with organic matter addition.
- Organic matter affects the densities of soil especially bulk density of soil, which in turn influences the soil porosity favorably.
- Organic matter increases the ability of the soil to resist erosion.

Improves Physicochemical Characteristics of Soil

- During decomposition of organic matter various organic acids and CO_2 liberate which help to reduce alkalinity of soil.
- Organic matter contributes to the cation exchange capacity (30-70% of the total) of soil.
- Organic matter acts as a buffering agent. Due to, such buffering effects, plant roots does not suffer from excessive acids, alkali or salts.
- Organic matter has solubilizing effect on some mineral compounds present in the soil. This is due to dissolution of mineral compounds by root exudates (CO_2 and organic acids).
- Organic matter acts as a chelate. The soluble chelate help to mobilize the micro-nutrients in soil increasing their ability to be adsorbed by plants.

Controls Soil and Water Pollution

- Organic matter temporarily adsorbs heavy metal pollutants (lead, cadmium etc.).
- Adsorption of pollutants helps clean, contaminated water.

Source of Energy and Growth Promoting Substances

- Organic matter serves as a source of energy for both macro and micro-organisms.
- Various organic substances like vitamins, antibiotics and growth promoting compounds namely auxin are produced by different microorganisms during decomposition of organic matter.

Detrimental Influence Over the Benefits of Organic Matter

Sometimes the benefits of organic matter in the soil are counterbalanced in certain situations by detrimental influences. They are as follows:

- Organic matter is an energy and carbon source for many diseases causing organisms.
- Excessive amounts of organic matter have a problem of mixing with the soil thoroughly and hinder easy planting.
- Burning off crop residues is harmful due to following reasons:
 - It removes the organic matter that protects soil against erosion,
 - Some ash that contains plant nutrients can be lost,
 - Leaching of soluble nutrients with ash and
 - Binding action is lost during burning.
- Numerous plants contain or produce phytotoxins during their decomposition. Such plants are undesirable for addition of organic matter to soil. Allelopathy is any direct or indirect effect of one plant on another through the production and release of toxic substances into environment.

ORGANIC MATTER DECOMPOSITION AND NUTRIENT MINERALIZATION

The decomposition of organic matter to form humus can be explained as follows:

- Micro-organism acts upon the easily decomposable substances like sugars, starches and water-soluble proteins. Crude protein, hemicellulose, and cellulose follow this. Lignin decomposes very slowly and dominates soil organic matter.
- The sugars, starches, hemicelluloses and cellulose oils, fats, resins are decomposed to CO_2 and water, and energy liberated is utilized by micro organisms.
- Proteins are decomposed to amino acid, amides and ammonium compounds. Ammonium compounds are oxidized to nitrites and nitrates. Phosphorus present as phytin, nucleic acid and phospholipids, are decomposed to liberate phosphorus as H_2PO_4^- ion. Sulfur containing aminoacids like cysteine and methionine are decomposed to liberate sulfur as sulphate. Complex organic forms are converted to their simple ionic forms like K^+ , Ca^{++} , Mg^{++} etc. (mineralisation) Simultaneously, microorganisms assimilate inorganic forms of nutrients themselves for synthesis of their cell protoplasm. (immobilization)
- During the earlier stages of decomposition of organic matter micro-organisms assimilate the inorganic forms of nutrients, Thus, their population increases

and decompose organic matter.

- When all the carbon compounds have been decomposed, the micro-organisms die due to lack of sufficient amounts of energy. Their bodies' decay and thus the complex forms of nutrients are reconverted into simple inorganic forms.
- Some proteins combine with organic compounds like lignins, tannin, humic acids etc. The clay adsorbs some proteins. These reactions protect proteins from microbial decomposition. All the organic material is thus converted to humus.

Reactions During Decomposition

Different organic residues contain different groups of organic compounds. So organic matter varies greatly in their rate of decomposition. Different constituents of organic residues may be listed in terms of ease of decomposition as follows:

- Sugars, starches and simple protein
- Crude protein
- Hemicelluloses
- Celluloses
- Fats, waxes, etc
- Lignin

rapid decomposition,



very slow decomposition

In spite of variable composition in different organic residues, the ultimate end products of decomposition are more or less similar.

When organic tissues are added to soil, three general reactions take place:

- The bulk of the material undergoes enzymatic oxidation with CO_2 , water, energy and heat as the major products.
- The essential elements such as N, P, S etc are released and /or immobilized by a series of specific reactions.
- Formation of compounds resistant to microbial action through a]. Modification of compounds in the original plant tissues and b]. Microbial synthesis

Simple Products of Decomposition Under Aerobic and Anaerobic Conditions

When organic residues undergo decomposition under aerobic and anaerobic soil conditions, the end products will be different. Under aerobic condition, the end products are CO_2 , NH_4^+ , NO_3^- , H_2PO_4^- , SO_4^{2-} , H_2O , and various essential plant nutrients like Ca^{2+} , Mg^{2+} , Fe^{2+} , Mn^{2+} , Cu^{2+} , Zn^{2+} etc. Under anaerobic soil conditions or waterlogged conditions, the end products are CH_4 , some organic acids (R-COOH) such as lactic acid, propionic acid, butyric acid, NH_4^+ , various amine residues (R-NH_2), H_2S and ethylene ($\text{H}_2\text{C=CH}_2$) and the resistant humic substances.

Decomposition Action of Soil Microbes

The organic solids are altered only very slowly until micro-organisms attack them. Bacteria, fungi and other micro-organisms that affect decomposition excrete a variety of enzymes to initiate breakdown of organic material. The decomposition rate is directly proportional to the number of microbes present. Microbes absorb

the nutrients released during decomposition - particularly nitrogen and carbon and use them for their growth and reproduction.

Presence of Nitrogen

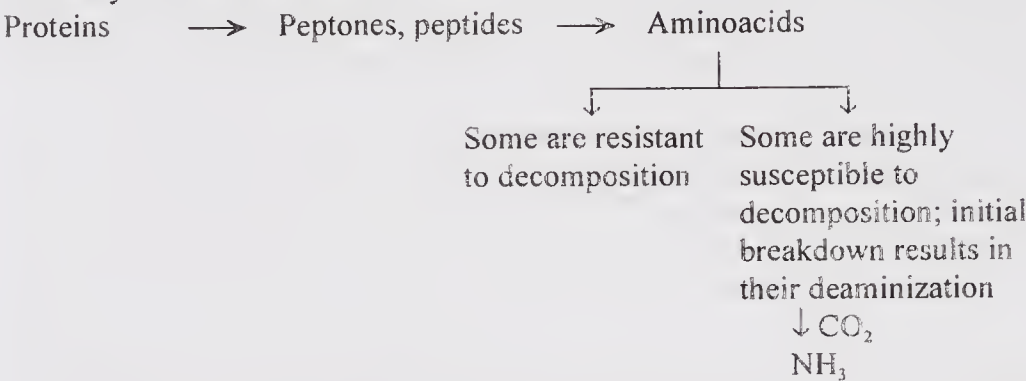
Nitrogen most often controls the rate of organic matter decomposition due to requirement of protein for new bacterial and fungal populations. The nitrogen content in the microbes and in the organic residues in proportion to their carbon content is called C:N ratio. Bacteria are heavy users of nitrogen (C:N ratio 4 or 5:1). If straw with its low nitrogen content (C:N ratio of 80:1) is incorporated into a soil low in nitrogen, bacteria will multiply slowly because the straw is a low nutrient food for the decomposing micro-organisms. Plants growing in a nitrogen deficient soil are deficient in nitrogen because the micro-organisms are able to make use of most available nitrogen before it can become accessible to plant root surfaces. The same is true for phosphorus and other nutrients. With the progress of decomposition, more amount of CO_2 is released into the atmosphere. This, narrows the C:N ratio in the organic matter. Therefore, the food is in short supply and some of micro-organisms like bacteria and fungi die. Other micro-organisms decompose their bodies (containing high amount of nitrogen) and liberate high amounts of nitrogen into soil solutions, which is subsequently available to plants.

Decomposition of Water Soluble Substances

When water soluble organic nitrogenous substances and sugars are subjected to decomposition, following reactions take place :

- $\text{Sugar} + \text{O}_2 \xrightarrow{\text{aerobic condition}} \text{CO}_2 + \text{H}_2\text{O}$
(Carbon and hydrogen containing substance)
- $\text{Sugar} + \text{O}_2 \xrightarrow{\text{Restricted supply of nutrients and oxygen}} \text{Aliphate or hydroxyl or alcohols (citric, or lactic acid etc.) (ethyl, methyl alcohol etc.) formic acid etc.)}$
- Through the action of fungi, alcohol and carbonic acids are produced as follows:
 - $\text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \longrightarrow \text{CHO}(\text{CHOH})_4\text{COOH} + \text{H}_2\text{O}$
Glucuronic acid
 - $\text{C}_6\text{H}_{12}\text{O}_6 + 3/2 \text{O}_2 \longrightarrow \text{C}_6\text{H}_8\text{O}_7 + 2\text{H}_2\text{O}$
Citric acid
 - $\text{C}_6\text{H}_{12}\text{O}_6 + 4 \frac{1}{2}\text{O}_2 \longrightarrow 3(\text{COOH})_2 + 3\text{H}_2\text{O}$
 - $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \longrightarrow 6\text{CO}_2 + 6\text{H}_2\text{O}$
- Under anaerobic condition, bacteria and yeast decompose sugars as follows:
 - $\text{C}_6\text{H}_{12}\text{O}_6 \longrightarrow 2\text{C}_2\text{H}_5\text{O}_3$
Glucose Lactic acid
 - $\text{C}_6\text{H}_{12}\text{O}_6 \longrightarrow \text{C}_4\text{H}_8\text{O}_2 + 2\text{CO}_2 + 2\text{H}_2$
Butyric acid
 - $\text{C}_6\text{H}_{12}\text{O}_6 \longrightarrow 2\text{C}_6\text{H}_5\text{OH} + 2\text{CO}_2$

compounds will react with acids and alkalis. Such compounds are said to be amphoteric. Enzyme protease attacks the protein molecules and hydrolyzes the peptide (CO-NH) bonds and release free amino acids via peptones and peptides. This may be indicated as below:



Since the N content of most protein is about 16% and since this is easily analyzed as NH₃ by Kjeldahl procedure, the crude protein content can be estimated by determination of the N content and multiplying by 6.25.

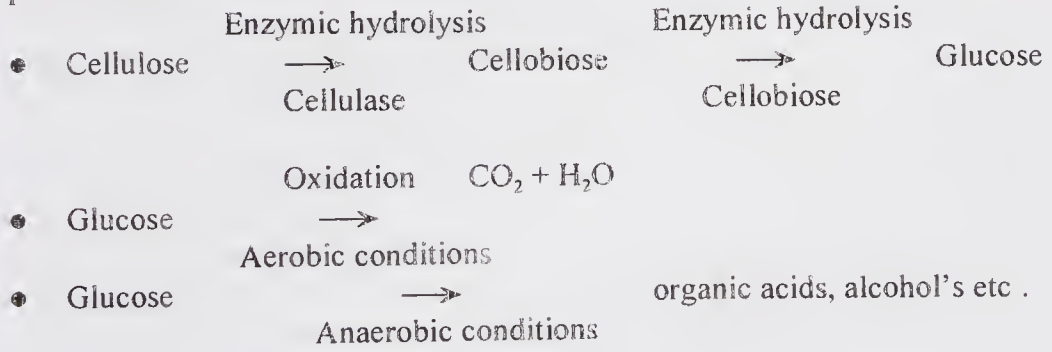
Lipids

Lipids are heterogeneous compounds of fatty acids, waxes and oils. These substances are soluble in either chloroform or benzene. The basic component of lipids is glycol. C₃H₈O₃. Neutral lipids are esters of fatty acids and glycerol, and are composed of one molecule of glycerol and three molecules of fatty acids. Waxes are esters of fatty acids and other alcohols. Phosphatides contain P, and upon hydrolysis will yield glycerol. Lecithin is a phosphatide . The P_i containing lipids are also called phospholipids. Lipids have limited solubility in water. Many of the lipids in plants and animals are associated with proteins and carbohydrate (e.g. glycolipids)

Cellulose

Cellulose is a carbohydrate composed of glucose units bound together in a long, linear chain by β linkages at carbon atoms 1 and 4 of the sugar molecules. A number of polysaccharides (xylans, polyuronides) are associated with the cellulose of plant cell wall.

Several micro-organisms are capable of decomposing cellulose in absence of O₂. The most common species being *Clostridium*. The main end products are CO₂, H₂, ethanol and various organic acids. The decomposition of cellulose take place as under:



compounds may take place with the formation of an oxygenated derivative of benzene. Lignin is insoluble in water, in most organic solvents and in strong sulfuric acid. Lignin is considered as an important source for the formation of soil humus, or humic matter. The high resistance of lignin to microbial decomposition makes it to accumulate in soil.

Organic Compounds Containing Sulphur

Organic substances carrying sulfur breakdown by micro-organisms through the process of mineralization. This may be presented as below:



→

Organic Sulphur oxidizing bacteria
sulfur
compounds

Organic Compounds Containing Phosphorus

Different micro-organisms mineralize phospholipids and other organic substances that carry phosphorus in presence of enzyme phosphatase. The final inorganic forms of phosphorus are $H_2PO_4^-$ and HPO_4^{2-} depending upon soil pH. Both these forms are available to plants.

SOIL ORGANIC MATTER AND PLANT GROWTH

Field based assessments of the effects of soil organic matter on plant growth are costly because these experiments are long term, and humus content is slowly changing in temperate climates. The major benefits of soil humus on plant growth result indirectly through improvement of soil properties, such as aggregation, aeration, permeability, and water holding capacity.

Contributes in Soil Fertility

- Organic matter contributes in soil fertility in a number of ways. It increases the cation exchange capacity and water-holding capacity, especially in light textured soils. Humic substances in association with soil clays are responsible for many chemical activities in soils. Humic substances have been reported to stimulate plant growth through their effect on metabolism and other physiological processes.
- During its oxidation, N, P and S are released and some of them may become available to plant in their growing season thus ultimately plant growth is increased by the addition of organic matter.
- The organic matter is the source of plant nutrients that are released in assimilable forms during microbial degradation. A major portion of N (95–99% of total), P (33–67% of total) and S (75% of total) in soils occurs in organic combinations, which mineralize to release the nutrients in inorganic forms to be used by plants. However, the mineralisation in most cases, is too slow to meet the full requirement of a high-yielding variety or crop. Nevertheless, it serves as a reservoir of plant nutrients, in promoting water storage and in regulating microbial activity.

Regulates Availability of Aluminium and Micronutrients

- Humic acids are capable of decreasing aluminium toxicity in soils. Acidic soils may contain soluble and free Al in amounts toxic for plant growth. Humic acid forms chelating complexes with excess Al, and thus reduces the concentration and chemical activity of free Al to the benefit of plant growth.
- Humic acid prevents the accumulation of large amount of micro-nutrients in the soil and, also releases them back in amounts suitable for plant growth. This is attributed to formation of humic acid-metal cation complexes thus storing metal cations for later use by plants.

Improves Physiological Functions of Plants

- Humus stabilizes soil structure, especially in soils of poor structural stability. Thus plant roots can proliferate in such soils.
- It has been reported that plants can take small degradation products of humic acids, nucleic acids and proteins up.
- Humic acid compounds can improve plant growth directly by acceleration of respiratory processes, by increasing cell permeability or by hormone growth action.
- Moderate amounts of humic acid are generally beneficial to root and shoot growth of corn plants. N content and dry matter production are stimulated by moderate amounts of humic acids.

MAINTENANCE OF SOIL ORGANIC MATTER

The maintenance of soil organic matter in mineral soils is perhaps the most important challenge to modern and traditional agriculture alike.

Encouraging crop yields and restricting tillage: By encouraging high crop yields, abundant residues can be returned to the soil either directly or by feed consuming animals. Also the rate of destruction of soil organic matter can be minimized by restricting soil tillage and by keeping at least part of crop residues at or near the soil surface.

Maintaining organic matter at a satisfactory level in a cultivated soil: Organic matter in soil is a dynamic material. It changes continuously as a result of microbial activity. It can be maintained by means of additions of new organic materials. This is an essential part of good soil management practices. It involves additions of crop residues, animal manure, domestic and industrial wastes. Maintenance of soil organic matter at a satisfactory level in cultivated soil is generally recognized as one of major problems in agriculture because supply of organic residues is limited and most of these materials are oxidized rapidly.

Growing grasses in arid and semiarid regions: It is also more difficult to maintain organic matter of soil in semi-arid and arid climate due to the high temperatures prevailing in these soils. In such soils growing grass is most effective in reducing losses of soil organic matter.

Green manuring: Green manuring is the practice of enriching the soil by turning under soil greens tender plants, usually legumes grown in the field. The

leguminous plants having comparatively high nitrogen content (2.5 to 3.0%) and narrow C:N ratio (10:1) decompose quickly. Besides acting as a source of nitrogen, green manuring coupled with phosphate fertilizers improves the soil organic matter. Broadly the practice of green manuring in India can be divided into two types- green manuring *in situ* and green manuring by collecting green leaves and tender twigs from other places.

Addition of crop residues: Crop residues provide varying amounts of organic carbon when these are incorporated into soil. In the soils where the above ground portion of crops have no immediate use, these may be profitably utilized in raising the organic matter content in soil. In India, this is not a common practice because they have many other uses. Root residues together with short stubble find themselves in the soil. This added carbon might constitute as little as 5% of total crop. Root residues have advantage over the top residues as a source of carbon. They are well mixed with soil. The polysaccharides and gums are well protected in the soil aggregates through cementing action and the organic matter level thus obtained.

Use of organic manure: Besides the above, other sources such as compost, bulky organic manure such as farmyard manure, urban and industrial waste, viz garbage, sawdust etc., and sewage effluent and sludge increases organic matter levels in soil. Since crop production capacity of soils is related to organic matter contents and cultivation results in loss of organic matter, organic matter content of cultivated soils is low. Further lowering of organic matter may result in decline in the inherent capacity of soils to produce crops. Therefore, much attention has been given to the soil management programs that aim at maintaining a satisfactory level of organic matter in cultivated soils. Since the rate at which carbon is lost from soil increases very rapidly with increased addition of organic matter, the maintenance of humus at a high level is not only difficult but also expensive. The problem becomes much more difficult in India especially in its warmer climate and arid conditions.

It is therefore, a pertinent question as to how much organic matter should be maintained in the soil. The ideal level is difficult to determine for a variety of conditions. But a satisfactory level of organic matter in any soil would be that which induces optimum crop yields under a reasonably good system of soil management. Over a number of years, a soil maintained under such a uniform management program will gradually attain equilibrium in humus content determined by tillage operations and environmental factor. It is not considered advisable to attempt an increase in this normal organic matter content at equilibrium. It is enough to maintain the status quo by frequent, though small additions of fresh organic matter that decays rapidly benefiting the immediate crop only. In the ultimate analysis, it is the decay of organic matter rather than its accumulation that contributes to soil productivity.

FACTORS AFFECTING THE AVAILABILITY OF SOIL ORGANIC MATTER

Climate

Climatic conditions, especially temperature and rainfall, exert a dominant

influence on the availability of organic matter in soil. Temperature and especially its diurnal variations influence type and quantity of vegetation in area, and consequently the nature and amount of organic materials added to soil by the natural process, the rate of their decomposition and synthesis of humus. Higher temperature stimulates microbial activity to a greater extent than plant growth. Thus the decomposition and availability of organic matter is increased. In cooler climates, the organic matter in soil is decayed at a slower rate although these soils are richer in organic matter.

With increase in rainfall, more growth of vegetation is possible, and consequently a greater accumulation of organic matter, provided the temperature is not too high. Organic matter level of soils increases till the annual rainfall is about 150 cm. Low temperature and high rainfall are conducive to accumulation of organic matter.

It has been found that the organic matter content of the soils of different world climate belts is more or less constant within narrow limits for each textural class of soils. Each soil seems to have a maximum capacity for humus and once when that capacity is reached, the humus content does not rise appreciably, however even much organic matter is added.

Natural Vegetation

Accumulation of natural vegetation on the surface of soil contributes to the organic matter in soil. Grasslands generally dominate the sub-humid and semi-arid region, whereas trees are dominant in humid regions. The total organic matter is higher in soils developed under grasslands than those of forests are. Apparently, the grasslands encourage a reduced rate of decay and thus a higher organic level than forest land.

Texture and Drainage

Soils high in clay and silt are generally higher in organic matter than coarse textured soils. The rate of organic residues returned to the soil is usually higher in the fine textured soils, and rate of oxidation may be somewhat slower than in sandy soils. Poorly drained soils, because of their high moisture content and relatively poor aeration, are generally much higher in organic matter than well-drained soils. Crumb structure and resistance to erosion are other soil factors favoring accumulation of organic matter.

Table 22.2. Organic matter content of Indian soils (per cent by weight)

	Organic carbon		Organic matter	
	Range	Average	Range	Average
Black soil	0.41–2.50	0.80	0.70–4.31	1.39
Red soil	0.14–2.39	0.66	1.39–4.12	1.14
Laterite soil	0.13–3.07	1.08	0.23–6.29	1.88
Alluvial soil	0.18–1.84	0.55	0.28–3.18	0.95

Cropping and Tillage

Cultivated soils decline rapidly with time than grassland soils. The decrease is not surprising because in nature (under grassland soils) all the organic matter produced by the vegetation is returned to the soil, whereas in cultivated areas much of the plant material is removed for human or animal food. Tillage practices break up the organic residues, bring the organic residues up so that they come in direct contact of soil organisms, thereby increasing their rate of decomposition.

Rotations, Residues and Plant Nutrients

A rotation of corn, oats, and clovers resulted in higher soil organic matter level as compared to continuous corn. The application of manure, lime, and phosphorous help in maintaining much higher organic matter levels. The increased return of organic matter through the added manure and increased crop residues accounts for this high organic matter level. Lime tends to protect organic matter from wasteful oxidation.

Amount of Organic Matter in Soil

The organic matter content of soils varies widely. The organic matter content of surface soils has been reported from traces to 10%. Peaty and swampy soils are known to contain up to 80% organic matter. Tropical soils are low in organic matter as it is quickly oxidized at higher temperatures. The content of organic matter usually diminishes with depth of soil. Cultivated soils contain less organic matter than virgin soils. Cultivation enhances oxidation and reduces organic matter. Wind and water erosion also brings about losses of organic matter in soils. The ranges of organic matter in major soils of India are given in Table 22.2.

Due to the low specific gravity of humus, as compared to that of the mineral part of the soil, the figures are very much lowered when the organic matter content is expressed as per cent by weight. But even when expressed as per cent by volume the humus content of soils is low. However, the effects of organic matter on soil properties are far greater than would be anticipated from the quantities present.

References and Suggested Readings

- Alexander, M. (1961). *Introduction to Soil Microbiology*. John Wiley and Sons, New York.
- Bear, F.F. (1964). *Chemistry of Soil*. Reinhold Publishing Corporation, New York.
- Flaig, W. and Sochtig, H. (1964). Einfluss organischer Stoffe auf die Aufnahme anorganischer Ionen. *Agrochimica*, 6 : 251–64.
- Gesering, J.E. (1973). *Soil Component*, Vol I. Organic Components. Springer Verlag, New York.
- Gesering, J.E. (1973). *Soil Component*, Vol I. Organic Components. Springer Verlag, New York.
- Jackson, M.L. (1962). *Soil Chemical Analysis*. Asia Publishing House, New Delhi.
- Jenny, H. and Ray Chaudhary, S.P. (1967). Effect of Climate and Cultivation on Nitrogen and Organic Matter Reserves in Indian Soils. ICAR, New Delhi.
- Jenny, H. and Ray Chaudhry, S.P. (1967). Effect of Climate and Cultivation on Nitrogen and Organic Matter Reserves in Indian Soils ICAR, New Delhi.
- Kanwar, J.S. (1976). *Soil Fertility – Theory and Practice*. ICAR New Delhi.
- Kononova, M.M. (1966). *Soil Organic Matter*. Pergamon Press, London.

McLaren, A.D. and Peterson, G.H. (1970). *Soil Biochemistry*. Marcel Dekker Inc., New York. Vol 1-5.

Waksman, S.A. (1963). *Humus Origin, Chemical Composition and Importance in Nature*, Bailliere, Tindall and Cox, London.

QUESTIONS

Q. 1. Fill in the blanks

- i) The C:N ratio of humus is approximately _____.
- ii) The humic substances make up about _____ per cent of the soil organic matter.
- iii) Drastic treatment of humus with hydrofluoric acid removes _____ matter.
- iv) Humus colloids are composed of carbon, hydrogen and oxygen in the form of _____, _____, _____ and polysaccharides.
- v) Enzymes reduce the _____ necessary to break the bonds of the organic materials.
- vi) When enzymes have been added to soils, they exist free and active only for a _____.
- vii) Enzyme _____ breakdown urea to water, CO₂ and NH₄⁺.
- viii) Enzyme _____ breaks the bond linking two amino acids.
- ix) Inspite of different composition in different organic residues, the ultimate end products of decomposition are _____.
- x) The protein molecules are composed of a long chain of amino acids having general structure _____.
- xi) Proteins are complex combination of _____.
- xii) N content of most protein is about _____ per cent.
- xiii) The basic component of lipids is _____.
- xiv) The P- containing lipids are also called _____.
- xv) Starch is the _____ of glucose.
- xvi) Leguminous plants have a narrow C:N ratio and _____ quickly.
- xvii) In cooler climates, the organic matter in soil is decayed at a slower rate although these soils are _____ in organic matter.
- xviii) _____ tends to protect organic matter from wasteful oxidation.
- xix) _____ soils contain less organic matter than virgin soils.

Answers

(i) 1:10 (ii) 60-80% (iii) humin (iv) polyphenols, polyquinones, polyuronides (v) activation energy (vi) short time (vii) urease (viii) protease (ix) more or less similar (x) H₂NCH(R)COOH (xi) amino acids (xii) 16 (xiii) glycol (xiv) phospho lipids (xv) polymer (xvi) decompose (xvii) richer (xviii) Lime (xix) Cultivated.

Q. 2. Choose the correct answer

- i) Plant tissue/ animals are the main source of soil organic matter.
- ii) In a plant, the percentage of cellulose and lignin increase/ decrease with

- maturity.
- iii) The conversion of organic forms of C,N,P and S to inorganic or mineral forms is called mineralization /immobilization.
 - iv) When fresh plant residues are added to the soil the C: N is wide/ narrow
 - v) Humic / non humic substances are more resistant to microbial attack.
 - vi) Polysaccharides, polymers and polyuronides are non humic/ humic substances .
 - vii) Up to 10% of the organic carbon in soils is in the form of polysaccharides/ cellulose.
 - viii) Humus is acidic/ alkaline.
 - ix) The colloidal surfaces of humus are negatively /positively charged.
 - x) In general, the decomposition is directly proportional/not proportional to the number of microbes present.
 - xi) Bacteria/ fungi are heavy users of nitrogen.
 - xii) Proteins, cellulose, hemicellulose are water insoluble/ soluble organic substances.
 - xiii) Twenty one/ eleven amino acids are usually found as protein constituents.
 - xiv) Waxes/ lipids are esters of fatty acids and other alcohol's.
 - xv) Hemicelluloses/ cellulose are attacked first by microorganisms.
 - xvi) A major portion of N,P and S in soils occurs in organic/ inorganic combinations.
 - xvii) The rate of destruction of soil organic matter can be minimized by restricting/ increasing soil tillage.
 - xviii) Trees/ grasslands are dominant in humid regions.
 - xix) Grasslands/ forest lands encourage a reduced rate of decay of organic residues.

Answers

(i) Plant tissue (ii) increase (iii) inorganic (iv) Wide (v) Humic (vi) non humic (vii) polysaccharides (viii) acidic (ix) negatively charge (x) directly proportional (xi) Bacteria (xii) insoluble (xiii) twenty one (xiv) Waxes (xv) Hemicelluloses (xvi) organic combinations (xvii) restricting (xviii) Trees (xix) Grasslands.

Q. 3. Define the following

(i) Humus (ii) Enzyme (iii) Allelopathy (iv) Amphoteric (v) Glycolipids (vi) Aromatization (vii) Lignification.

Q. 4. Differentiate between

(i) "Organic matter and Humus (ii) Mor and Mull (iii) "Loss on ignition" and "Dry combination method" of determination of organic matter in soil (iv) Fulvic acid and Humic acid (iv) End products of decomposition of organic residues under Aerobic and Anaerobic conditions (v) Decomposition of sugars under Aerobic and Anaerobic conditions.

Q. 5. Write short notes on

(i) Carbon cycle (ii) Kononova's concept of humus formation (iii) Polyphenol theory of humus formation (iv) Detrimental influence on the benefits of organic

matter (v) Decomposition action of soil microbes (vi) Decomposition of water soluble nitrogenous compounds.

Q6 Comment on the following statements

- i) Organic matter is a dynamic material in the soil.
- ii) Lignins are very resistant to microbial decomposition.
- iii) There is no accurate method available for the determination of organic matter.
- iv) Walkely and Black method has been adopted as a routine procedure for the determination of organic matter content of a soil.
- v) It is desirable to mix straw with a small quantity of ammonium sulfate.
- vi) In soil, organic residues of plant and animal origin undergo diverse changes
- vii) Humic substances have been classified into three chemical groups.
- viii) Humus imparts a higher degree of aggregation in soils.
- ix) Humus is capable of reacting with soil minerals and increases nutrient availability.
- x) Organic matter helps to reduce alkalinity of soil.
- xi) Organic matter acts as a buffering agent.
- xii) Organic matter helps clean, contaminated water.
- xiii) Burning off crop residues is harmful.
- xiv) Nitrogen controls the rate of organic matter decomposition.
- xv) Plants growing in a soil deficient in N, P, K have a low content of these nutrients.
- xvi) Lignin is accumulated in soil.
- xvii) Humic substances have been known to stimulate plant growth.
- xviii) Humic acids are capable of decreasing aluminium toxicity in soils.
- xix) Humic acid prevents the accumulation of large amount of micro-nutrients in the soil.
- xx) Maintenance of soil organic matter at a satisfactory level in cultivated soil is recognized as one of major problems in agriculture.
- xxi) Root residues have advantage over the top residues as a source of carbon
- xxii) Organic matter content in cultivated soil is low.
- xxiii) The maintenance of humus at a high level is difficult and expensive particularly in our country.
- xxiv) It is not considered advisable to attempt an increase in the normal organic matter content at equilibrium.
- xxv) Each soil seems to have a maximum capacity for humus content.
- xxvi) Poorly drained soils are generally much higher in organic matter than well drained soils.
- xxvii) Tillage practices increase rate of decomposition of organic matter.

Q. 7. Answer the following in brief

- i) What is the composition of a plant.
- ii) Give the scheme of classification of organic residues in soil.
- iii) What does a low C:N ratio (10:1) indicate in a soil in comparison to a wide

C:N ratio (say 40:1).

- iv) What is the percentage composition of well digested humus.
- v) What is a quinone protein complex.
- vi) What is the fate of free enzymes in soil.
- vii) How does soil enzymes work in soil.
- viii) Enlist five common soil enzymes and reactions in which they are involved
- ix) Enlist different constituents of organic matter in terms of ease of their decomposition.
- x) How does presence of nitrogen influence rate of organic matter decomposition.

Q. 8. Answer the following in detail

- i) Explain the fractionation scheme of soil organic matter.
- ii) Explain the decomposition of organic matter to form humus .
- iii) Explain the role of soil organic matter in maintaining soil productivity.
- iv) Illustrate the decomposition of following organic substances. Also give equations.
 - a) Hydrolysis of proteins.
 - b) Decomposition of cellulose.
 - c) Breakdown of starch.
 - d) Mineralization of sulfur.
- v) Describe the beneficial effects of organic matter on plant growth.
- vi) Describe the factors affecting the availability of organic matter in soil.

Q. 9. Give diagrammatic view of the following

- i) The approximatic composition of carbon in soil humus.
- ii) Carbon cycle.



Biofertilizers

BIOFERTILIZERS or microbial inoculants are the products containing living cells of different types of micro-organisms which have an ability to mobilise nutritionally important elements from non usable to usable form through biological process. Preparations containing these can be considered as microbial fertilizers. Biofertilizers may be referred as inoculants after the name of micro-organisms they contain, viz. *Rhizobium* inoculant or *Azospirillum* inoculant.

Microbial inoculants are biologically active products containing active strains of specific bacteria, algae, fungi, alone or in combination, which may help in increasing crop productivity by way of helping the biological nitrogen fixation, solubilization of insoluble fertilizer materials, stimulating plant growth or in decomposition of plant residues. (Verma and Bhattacharyya, 1994)

The term bacterial (microbial) fertilizers refers to preparations containing primarily active strains of micro-organisms mainly bacteria in sufficient numbers (Tilak, 1993).

A biofertilizer is an organic product containing a specific micro-organism (microbial inoculant) in concentrated form (10^7 to 10^9 g⁻¹) which is derived either from the nodules of plant roots or from the soil of root zone (Rhizosphere).

Biofertilizers are used: (i) to fix atmospheric nitrogen available in large amounts and thus supplement the organic and inorganic fertilizers. (ii) to solubilize plant nutrients like phosphates, (iii) to stimulate plant growth through synthesis of growth promoting substances and (iv) to help in the uptake of available nutrients. Biofertilizers are biological in origin and serve to supply nutrients for plant growth.

Biofertilizers give better responses under irrigated conditions but they may be quite useful even in dryland agriculture. Dryland agriculture stretches over 100 m ha in India. It produces 44% food and supports 40% population. Cultivation of more than 90% of the coarse cereals, 80% groundnut, 85% pulses, 70% cotton, 55% rice and 22% wheat is concentrated in rainfed areas (Katyal *et al.* 1994). Average productivity of foodgrains (coarse cereals plus pulses) in rainfed areas is around 680 kg/ ha. The comparable yields of irrigated crops are two to three times higher. Organic manure and biofertilizers are vital natural resources, which can be utilized to boost the overall nutrient turn over.

Significance of Biofertilizers

- Global turnover of nitrogen per year is estimated to be around 200 million tons, out of which two third comes from biological sources. Nitrogen available from chemical fertilizers is estimated to be 80 million tonnes. Organic manures and biofertilizers have been universally identified as two important renewable sources of plant nutrients. Organic manures being bulky in nature, required

in large quantities and is costly, also not available to that extent. Therefore, for augmentation of plant nutrition at cheaper rate, the biofertilizers are the ultimate important renewable source.

- Biological nitrogen fixation contributes 69% of the global N- fixation and non-biological process account for 3%. Legume- *Rhizobium* symbiosis is the most significant as it supplies 80–90% of the total nitrogen requirement of legumes and increases grain yield by 10–15% under field conditions (Verma and Bhattacharyya, 1990). Nitrogen fixation capacity of legumes is harnessed by inoculating the crops with efficient *Rhizobium* strain.
- The use of blue green algae provides 25–50 kg N/ ha to rice crop. Application of one crop of *Azolla*, (before and after transplanting rice), increases rice grain yield. Blue green algae supplies plant growth promoters.
- Field trials conducted to study the influence of *Azotobacter* and *Azospirillum* inoculation on several non-leguminous crops experienced 5-15 per cent increase in yield and a nitrogen contribution of about 25 kg /ha. By the use of *Azospirillum* as a seed inoculant, savings of 20-30 kg N/ ha could be achieved in crops like barley, sorghum and millets (Subba Rao *et al*, 1980).
- The use of phosphobacterin has been found to increase the efficiency of ground rock phosphates and superphosphate applied in neutral to alkaline soils. Phosphobacterised seeds give higher yields and increases efficacy of applied phosphorus.
- Vesicular - Arbuscular Mycorrhizae (VAM) has a prominent role in phosphate availability through increased uptake of soil phosphorus.

Merits of Biofertilizer Use

- There is no harmful effect on soil fertility or plant growth since biofertilizer is a natural product carrying living microorganisms.
- It is required in smaller quantities since each gram of carrier of a biofertilizer contain approximately 10 million cells of a specific strain (500 g/ha material may be sufficient).
- Tandon (1991) reported estimates of nitrogen equivalent potential of important biofertilizers. In general, *Rhizobium* inoculation may have fertilizer equivalent of 19–22 kg N /ha, *Azotobacter* and *Azospirillum* 20 kg N /ha, Blue Green Algae may fix 20–30 kg N /ha and *Azolla* may provide 3–4 kg N / per ton of *Azolla*. Obviously, even if 50% of the potential of these biofertilizers could be realised under field conditions, their use would be cost effective.
- Use of biofertilizer leaves a beneficial residual effect on soil fertility.
- Use of biofertilizer may favorably influence root growth, crop stand; hasten flowering and crop maturity to a certain extent.
- *Rhizobium* possesses better tolerance to salt and pH under various ecological conditions. Crop plants thus possess better adaptability to different agro-climatic situations.
- Use of biofertilizers is economical with a high cost: benefit ratio, without risk (Table 23.1).
- If the strain of a bio-inoculant is properly evolved, it might work simultaneously as a 'biofertilizer' and a 'biopesticides', as was observed in

Table 23.1. Economics of biofertilizer application at farmer’s field

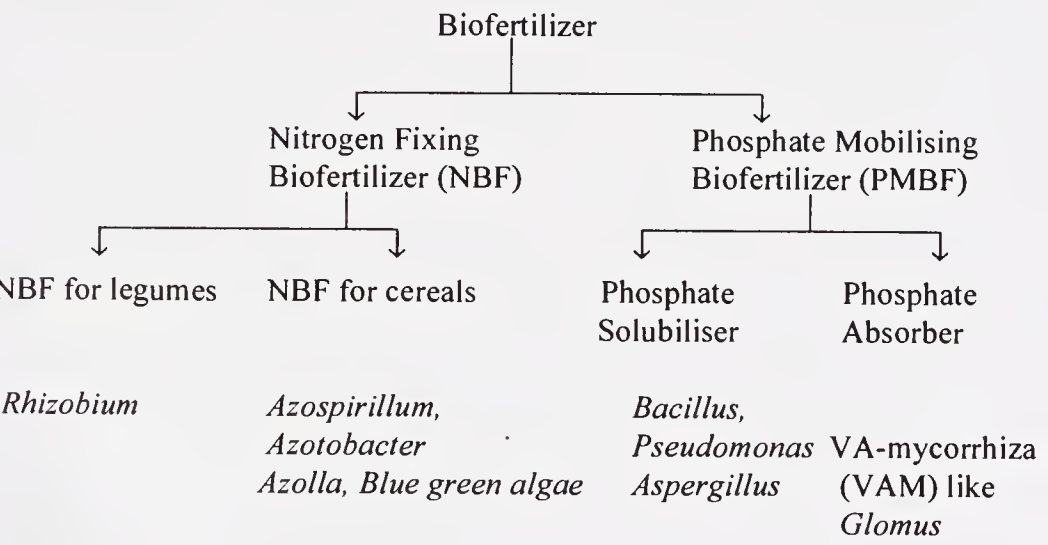
Particulars	Rainfed groundnut	Irrigated hybrid sorghum
Number of demonstrations	34	5
Area covered (ha)	29.2	2.2
Rate of Rhizobium application (gm/ha)	500	500
Method of Rhizobium application	Seed treatment	Seed treatment
Increase in yield over control (kg/ha)	117	147
Cost : benefit ratio	1:94	1:29

Cost of biofertilizer : Value of produce: Groundnut Rs 1 /kg, Jowar Rs 2.50 /kg
Source: Shah and Joshi (1986)

- the case of *Azotobacter* strain 1006 by Shah and Joshi (1986). The said strain was claimed to have shown potential to inhibit seed borne pathogens in some cereals.
- Biofertilizers like *Azospirillum* and *phosphobacterin* produce growth promoting substances which have been reported to promote number and length of roots, besides shoot growth.

CLASSIFICATION OF BIOFERTILIZERS

Depending upon the nutrients provided, Verma and Bhattacharyya (1994) classified biofertilizers as follows:



Asymbiotic nitrogen bacteria: Among the asymbiotic nitrogen fixing bacteria *Azotobacter*, *Beijerinckia*, *Azospirillum* and photosynthetic nitrogen-fixing blue green algae are important. In waterlogged paddy soils blue-green algae are important source of nitrogen.

Fast and slow growing strains of rhizobia: Rhizobia may be divided into two groups based on their growth habits, i.e. the fast growing strains and the slow

growing strains. The fast growing strains produce acid on the yeast-mannitol-agar and include *R. phaseoli*, *R. trifolii*, *R. leguminosarum* and *R. meliloti*. The slow growing strains produce alkali on yeast-mannitol agar. It includes *B. japonicum*, *R. lupini* and *shizobia* of cowpea miscellany group. There is a difference between the homology of DNA of *B. japonicum* and *R. leguminosarum*, which also justify the separation of rhizobia into slow and fast growing strains. (Deley and Russel, 1965).

Biofertilizers in dryland agriculture: Biofertilizers relevant to dryland agriculture can be grouped into different categories based upon the type of organisms (bacteria or fungi) or whether the organism is symbiotic or free living. *Rhizobium*-a symbiotic bacterium benefits a number of rainfed pulses and some oilseed crops (e.g. groundnut and soybean). *Azospirillum* and *Azotobacter* - both non-symbiotic bacteria, are potential biofertilizers that are capable of contributing N to dryland cereals and millets. VAM (*Vascicular Arbuscular Mycorrhiza*) - best known fungus biofertiliser is symbiotic in nature.

Rhizobium: *Rhizobium* lives in the nodules of host plants belonging to the family of leguminosae. The plants are able to use some of the nitrogen fixed by microbes. This is called symbiosis. The seeds of legumes are inoculated with *Rhizobium* culture and are sown. When the legume plant is turned under the soil, the nitrogen becomes available to the succeeding crops. Some of the nitrogen passes into the soil by ploughing. The amount of nitrogen fixed varies with the strain of *Rhizobium*, the plant species and environmental conditions.

Azospirillum: *Azospirillum* is commonly found in roots of cereals and grasses. *Azospirillum* has a low energy requirement, abundant establishment in the roots of cereals and tolerance to high temperature (30–40°C). *Azospirillum* are mesophilic and reported in crops grown in acidic to alkaline range. *Azospirillum* inoculum can survive in saline alkaline conditions. It is thus suited to tropical conditions. It is seen that total nutrient assimilation (NPK) in *Azospirillum* inoculated plants is higher than the uninoculated plants. Bacterization resulted in yield increases, which may be attributed to plant growth promoting substances, and enhanced nitrogen assimilation by plants. (Wani *et al.* 1991)

Azotobacter: *Azotobacter* is a free living, chemoheterotrophic nitrogen fixing bacteria. Crops receiving moderate fertilizer nitrogen alongwith *Azotobacter* inoculation increases crop yields in proportion to increased crop yields through fertilization but without nodulation. This indicates possibility of reducing fertilizer nitrogen application by inoculating the crop. *Azotobacter* inoculation has lead to beneficial effects under dryland crops (Table 23.2).

Azolla: (*Azolla pinnata*) and Blue green algae: Azolla is a water fern. Azolla

Table 23.2. Benefits of Azotobacter inoculation in some dryland crops.

Crop	Per cent yield increase over control
Sorghum	15–20
Pearlmillet	0–27
Cotton	11–16

Source: Venkataraman and Tilak (1990)

is seen associated with rice field. A blue green algae (*Anabeana azolle*) living in the epidermal cavity of the lower side of the leaf of *Azolla* in symbiotic association fixes atmospheric nitrogen. This symbiotic association of *Azolla pinnata* and *Anabeana azolle* is termed as *Azolla Anabeana* complex. The algae fix atmospheric nitrogen for azolla and in exchange the plant provides home and food to the algae.

Composition of Azolla: Decomposed Azolla contains the following plant food:

(i) Nitrogen 4–6%, (ii) Phosphorus 0.5–0.9%, (iii) Potash 2–6%, (iv) Calcium 0.4–1%, (v) Magnesium 0.5%, (vi) Manganese 0.11–0.16%, (vii) Iron 0.06–0.16% and (viii) Water >90%.

Method of growing Azolla: *Azolla* grows well when the temperature is between 14°C to 35°C (optimum temperature 28°C), pH between 6 to 8 and depth of water 8 to 10 cm in the field. Standing water and phosphorus are required for rapid growth of *Azolla*. It should be protected from leaf eating insects and snails by proper application of insecticides. *Azolla* is grown by spreading 200 to 500 kg/ha of fresh *azolla* in the field. After 20 to 25 days, green *azolla* is incorporated by ploughing after dewatering the field. *Azolla* can be grown along with paddy. Nitrogen will be added even if it is not incorporated. *Azolla* can fix 600 to 800 kg N/ha.

Benefits of Using Azolla

- *Azolla* contains high percentage of nitrogen. It increases the organic matter content of the field and thereby improves soil structure and water holding capacity etc.
- It releases plant nutrient slowly like slow releasing fertilizer. There is no leaching loss.
- Paddy yield increases by 15–25% when *Azolla* is applied.

Blue green algae: Blue green algae (BGA) or cyanobacteria are photosynthetic nitrogen fixing organisms. Common genera found in Indian soils include *Anabaena*, *Nostoc*, *Aulosuria*, *Calothrix*, *Tolypothrix*.

Algae are applied at the rate of 10 kg /ha over the standing water in the field one week after transplantation. The field is kept waterlogged for 7 to 10 days after algae application. Application of BGA increases paddy yields by 15 to 20% under submerged conditions. Algae fix nitrogen from air in presence of sunlight.

Phosphate solubilising micro-organisms: Some hererotrophic bacteria and fungi are known to have the ability to solubilise inorganic P from insoluble sources. Important phosphate solubilising organisms are *Pseudomonas striata*, *Bacillus polymxa*, *Aspergillus awamori*, *Penicillium digitatum*.

Vesicular Arbuscular Mycorrhizae: Mycorrhiza is a mutualistic symbiosis between plant roots and certain soil fungi. It plays an important role in P cycling and its uptake by the plant. Among mycorrhizas, VAM has good potential in improving nutrient cycling. VAM are formed by non-septate zygomycetous fungi belonging to the genera *Glomus*, *Gigaspora*, *Acaulospora*, *Entrophospora*, *Sclerocystis*. These are obligate symbionts (depend on living plants). Soil type, host variety, VAM strain and biotic and abiotic factors govern crop response to VAM inoculation. Yield increases with application of VAM has been found in dry and green forage, chillies and groundnut.

ISOLATION, IDENTIFICATION AND EVALUATION OF ORGANISMS USED AS BIOFERTILIZERS

It has been estimated that above each hectare of land there is about 80,000 tonnes of nitrogen available in atmosphere. Most of the cultivated tropical soils have good population of rhizobia capable of nodulating legumes. To ensure maximum benefit of rhizobia, following conditions should be met:

Efficient strains: Efficient and competitive strains of rhizobia ensure maximum nitrogen fixation. Ineffective strains may lead to poor nodulation. Qualities of efficient microbial strains: An efficient microbial strain should possess following qualities.

- Competitive ability over other strain for nodulation of the host.
- Nodulation and N fixing abilities in presence of soil N and over a range of environmental conditions.
- Ability to multiply in broth and survive in inoculant carrier and when incorporated in seed pellets, to migrate from the initial site of inoculation, to colonize away from the influence of host roots and persistence in soil.
- Ability to survive adverse physical conditions such as dessication, freezing and strain stability during storage.

Phosphorus supply: Deficiency of phosphorus leads to decreased nodulation. Application of phosphate fertilizers under such conditions results in the enhancement of yield.

Micronutrients: Application of micronutrients has been found to increase nodulation and plant dry matter yield.

Optimum conditions: High temperature and low moisture are not suited for the establishment of the inoculant. Excess waterlogging, unsuitable pH, predators and pests may affect the potentiality of *Rhizobium* strains.

Rhizobial Inoculants

Inoculant should be of efficient *Rhizobium* strain. The most ideal way of determining the efficiency of strain is to conduct growth tests. With the knowledge of cross inoculation group it has been possible to produce composite culture and select efficient strains.

The nitrogen-fixing ability of a rhizobial strain can be determined by growing plants in sand cultures devoid of nitrogen sources. Under these conditions dry matter and protein contents of plants are directly related to the ability of *Rhizobia* to provide nitrogen. However, several workers observed that strains showing equal efficiency under the laboratory conditions might show marked differences in their ability to nodulate under field conditions. Burton (1967) suggested the following reasons for it:

- Differences of strains related to soil fertility level and pH of the soil.
- Inherent variations in rhizobial efficiency that come in the viewpoint under the nitrogen stress provided by the plant.
- Variations in the ability of the nodulating bacteria to resist the antagonistic microflora.
- Differences in competitive qualities of the rhizobial strains.

Mother culture: Availability of mother culture may form the basis for the

production of inoculum. Proven strains may be obtained from recognised institutions like, Indian Agricultural Research Institute (IARI), Jawaharlal Nehru Krishi Vishwa Vidyalaya, Mahatma Phule Agriculture University, Tamil Nadu Agricultural University, International Crops Research Institute for Semi- Arid Tropics, or Commercial Biofertilizer Producers in India.

Isolation of Rhizobium: Clean nodules are individually crushed in sterilize water and the resulting suspension is streaked on Yeast Extract Mannitol Agar (YEMA) plates, poured 24 hours earlier to ascertain the sterility of plates and culture media.

Cross-inoculation group: The leguminous species develop certain definite preference for certain kinds of nodule bacteria and vice versa. Each of these groups of legumes and their specific rhizobia constitute a cross-inoculation group. It is seen that (i) with each cross-inoculation group a *Rhizobium* isolated for one legume member of the group would nodulate all other members of that group, and (ii) rhizobia isolated from one plant in cross-inoculation group would not nodulate plants from other groups. It is also observed that nodulation responses are as fixed and definite as any other property of the rhizobial cell and thus it could be used in classification. Seven cross-inoculation groups are recognized on the basis of ability of rhizobia to form nodules with legume plants. They are listed in Table 23.3.

Identification of organisms used as biofertilizers: Host legume reaction is a valid test in the identification of rhizobia and its differentiation from agro-bacteria.

Growth and colony characteristics on yeast-extract mannitol agar: The rhizobial colonies appear raised, wet, shining and somewhat translucent with smooth edges. The consistency of the colonies may vary depending upon the source and *Rhizobium* sp. (Vincent, 1970).

Infection mechanism in legumes: *Rhizobium*- legume symbiosis depends on the entry of the *Rhizobium* into the root system of the legume. It takes place in following steps:

Recognition of host: Infection and nodule formation are host specific phenomena. Legume species, which are nodulated by some rhizobial isolates, are not nodulated by other isolates.

Curling of root hairs: The attachment of *Rhizobium* to legume leads to interactions leading to nodulation. Curling of root hairs after inoculation with

Table 23.3. Cross-inoculation groups of Rhizobium

Rhizobium species	Cross-inoculation group	Legumes
<i>R. trifolii</i>	Clover group	<i>Trifolium</i>
<i>R. meliloti</i>	Alfalfa group	<i>Melilotus, Medicago, Trigonella</i>
<i>R. phaseoli</i>	Bean group	<i>Phaseolus</i>
<i>R. lupini</i>	Lupine group	<i>Lupinus, Ornithopus</i>
<i>R. leguminosarum</i>	Pea group	<i>Pisum, Vicia, Lens</i>
<i>R. japonicum</i>	Soybean group	<i>Glycine</i>
<i>Rhizobium</i> sp. (miscellany)	Cowpea (miscellany) group	<i>Vigna, Arachis</i>

Table 23.4. Cultural and biochemical characteristics using different methods of identification of bacterial strains

Method	Bacterial strains	Author
Changes in reaction of growth medium Yeast-extract mannitol medium KH ₂ PO ₄ 0.5g MgSO ₄ :7H ₂ O 0.2g NaCl 0.1g Mannitol 10.0g Yeast extract 1.0 g Distilled water 1,000 ml Congo red(1%) 2.5ml (only for solid medium during isolation) yest extract mannitol medium with bromothymol blue Rhizobium strains grown on	Strains of <i>R. trifolii</i> , <i>R. meliloti</i> , <i>R. leguminosarum</i> and <i>R. phaseoli</i> -Produced acid in the medium Strains of <i>R.japonicum</i> , <i>R.lupini</i> and <i>Rhizobium</i> sp. (Cowpea group)- produced alkalinity	Norris and Date (1976)
Growth on Hofer’s alkaline medium(broth) KH ₂ PO ₄ 0.5g MgSO ₄ :7H ₂ O 0.2g NaCl 0.1g CaCO ₃ 0.05g Yeast extract 1.0g Mannitol 10.0g Distilled water 1,000 ml	Suitable for differentiating Rhizobia from agrobacteria None of rhozobia grew in moderately alkaline medium (pH10) At pH 11, agro bacteria grow but not medic rhizobia	Allen and Allen (1958)
Growth on peptone-glucose agar Glucose 5.0g Peptone 10.0g Agar 15.0g Distilled water 1,000 ml	Rhizobial strains showed poor or no growth whereas agrobacteria grew well	Klaczko wska et al. (1968)
Tolerance to high concentration Yeast extract mannitol medium containing 2% NaCl	<i>Agrobacterium radiobacter</i> , and <i>A. tumefaciens</i> and a few strain of medic rhizobia were able to grow whereas rhizobia did not grow	Graham and Parker, (1964)

Rhizobium occurs first. The secretion of the bacteria causes root hair curling. Several works have suggested that the tryptophan produced in the roots of the legumes be converted into IAA by rhizobia.

Formation of infection thread: It is suggested that root hair cell wall becomes invaginated to form the infection thread. This is due to incorporation of bacteria into the primary host wall material. This infection thread is basically from host origin. It is composed of cellulose and hemicellulose substances. Various theories have been suggested regarding the mode of entry of *Rhizobium* into the root hair.

Development of nodule: During nodule development, plant and bacterial genes produce nodulins. Nodulins are nodule specific proteins produced during nodule development. Nodulins may be divided into three categories.

- Protein responsive for maintenance of nodule structure.
- Proteins that support bacteroid function and facilitate N-fixation.
- Enzymes induced in specific nitrogen assimilates and carbon metabolism of nodules.

Two Types of Nodules

- C-nodulins, where protein is common to all nodulins.
- S-nodulins, are species specific nodulins.

Nodules found in leguminous plants may be effective or non-effective. Effective nodules are fewer, larger in size with a pink central zone, which is the area of active nitrogen fixation. The host plant in all these cases is healthy in appearance. Nodules may be simple or compound, round, elongated or club shaped, single or in clusters and are generally located about the main root and first formed lateral roots. They range in size from 2 to 6 mm for clover and 3 to 10 mm for lucerne. Ineffective nodules are small; white, very numerous and scattered over the entire root system. The plants are generally yellow in color. (Tilak, 1993).

Host specificity: Depending on the host specificity and occurrence of strain the effectiveness of the association may vary. Due to strain specificity only a few per cent of the infected root hairs may give rise to nodules. It has been established that different varieties of different legumes have specific bacterial preference. The nitrogen fixed by *Rhizobium* depends on the compatibility between the host and the bacterium and climate. The difference in host interactions is attributed to genetic constitution of legumes as well as *Rhizobium* (Lie and Mulder, 1971).

Carrier material used in biofertilizers: The medium in which *Rhizobia* are allowed to multiply is called carrier. Unless a good carrier is identified the efficiency of biofertilizer may not be achieved to the desired level. Carrier material should possess following qualities. i. It should be non-polluting and non-toxic. ii. It should be biodegradable (should not possess long residual effects). iii. It should have a high water holding capacity and capable of maintaining high viable counts. The peat- based inoculants contain a high amount of organic matter, which acts as a buffering agent. Common carrier materials are presented in Table 23.5

Mixing of broth culture with carrier and curing: For preparation of carrier based inoculants the rhizobial broth culture must attain a minimum population of 10^9 cells /ml. The carrier material is sun-dried up to a moisture level of 5%. Heat drying of any carrier material leads to some deleterious effect on the organism used for multiplication. Better growth of rhizobia is obtained in sterile carrier. After mixing the carrier with broth culture carrier is kept for curing. During this time the rhizobia get acclimatized with the carrier. After curing the inoculant is ready to be packed in polythene bags. Directions for use of inoculants must be printed on the packet. Fig 23.1 (a) indicates preparation of culture. Flow Diagram Showing Preparation of Bacterial Culture in Fig 23.1 (a).

Incubation and storage: Inoculants must be incubated for a week in a room where the temperature must be congenial for the growth of the organism which is

Table 23.5. Few carrier materials and suitable inoculants

Carrier materials	Suitability	Limitations	Suggested by
Peat based carrier materials	Suitable for inoculant production	Susceptible to high temperature and drought conditions Non availability	Chao W.L. et al. (1984)
Oil based <i>Rhizobium phaseoli</i> inoculants	Substitute for peat based carrier materials	Can tolerate temperature and drought stresses	Kremer and Peterson (1982)
Synthetic carriers calcium alginate beads	For <i>Azospirillum brasilense</i> <i>Pseudomonas fluorescens</i> and <i>Frankia</i>	Support high bacterial number at room temperature, easy biodegradability in soil	Dommergues et al. (1990)
Dilution of broth culture	Fast growing bacteria grow well		Jauhri, et al. (1988)
Molasses	Slow growing bacteria grow well		Jauhri, et al. (1988)
Lignite, charcoal, pressmud, agro industrial wastes, composts	Carrier for legume inoculants		Poi S.C et al. (1985)
Spent mushroom compost mixed with finely powdered charcoal (3:1)	Used for commercial production for rhizobium and <i>Azotobacter</i> inoculants	It has increased the visible counts as well as shelf life during storage	Bahl et al. (1989)
Agro industrial wastes	A suitable replacment for other carrier materials	Proliferation of contaminants needs to be checked	Jauhri K.S. (1988)
Charcoal	Suitable for <i>Rhizobium</i> , <i>Azotobacter</i> , <i>Azospirillum</i>	Improve the quality of carrier materials such as sugarcane, pressmud and soil or the preparation of bacterial inoculants	Tilak and Subba Roa (1978) Jauhri and Koshy (1984)
Mixture of soil and charcoal or pressmud and charcoal	Blue green algae and others	Improves storage of inoculants	Jauhri et al. (1979)

used in the preparation of the inoculant. During this period the bacterium multiplies and reaches to a required standard. The packet may then be stored in a cold room.

Quality control of rhizobial inoculants: Inoculants quality refers to the number of specific effective rhizobia in the inoculant. It also includes strain testing, control of broth before incorporation into the carrier and control of cultures during the period of storage.

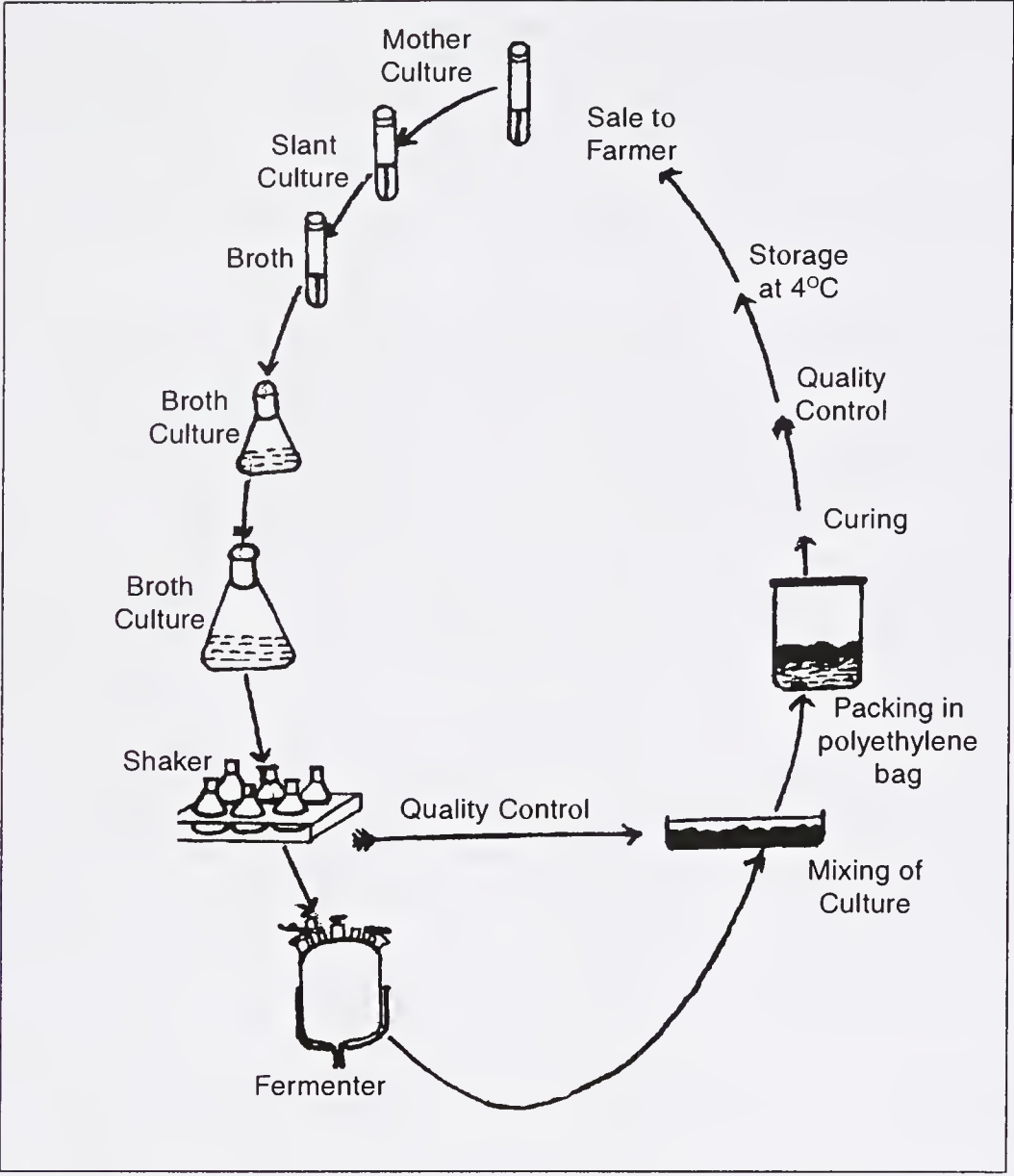


Fig. 23.1 (a). Flow diagram showing preparation of bacterial culture

Method of Application of Rhizobium Inoculants

Carrier -based cultures are suspended in 10% sugar or *gur* (jaggery) solution in water. The sugar or *gur* solution is boiled and cooled before the culture is sprinkled on the seeds and the seeds are thoroughly mixed so as to have a uniform coating. A count of 1,000 viable cells per seed is to be attained at the time of treating the seed. Fig. 23.1 (b) indicates use of culture. Flow Diagram showing use of culture in Fig. 23.1 (b).

Method of Seed Inoculation

A 10% sugar solution is prepared to serve as a sticker of *Rhizobium* cells to seeds. This solution is sprinkled on seeds and then the seeds are spread on a polythene sheet and mixed uniformly. The contents of the inoculant packet are sprinkled uniformly on the sticker-coated seeds and mixed simultaneously. The

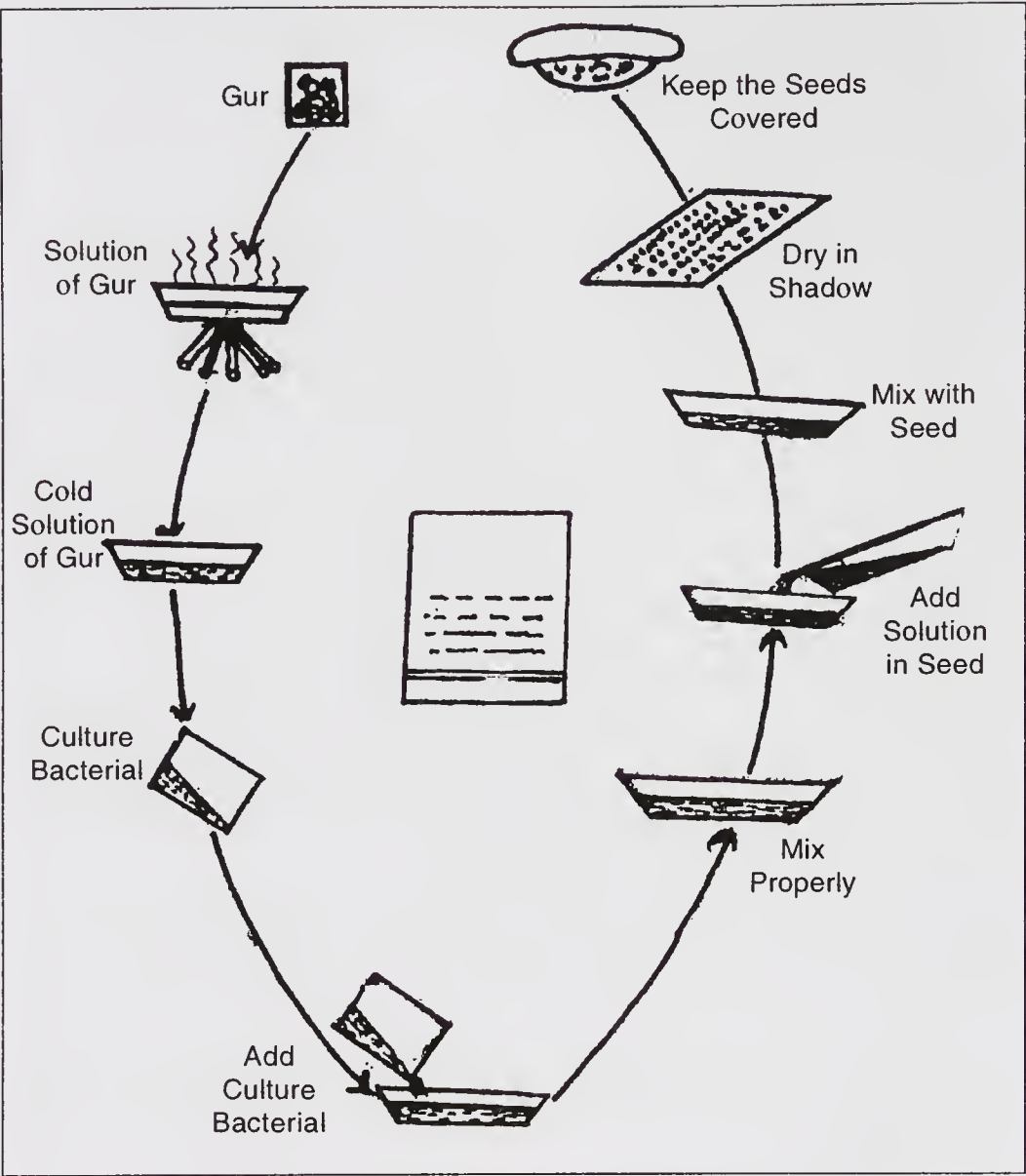


Fig. 23.1 (b). Flow diagram showing use of culture

seeds are spread uniformly for drying in shade on a gunny bag. The seeds are sown immediately. In order to protect Rhizobia from effects of acid fertilizers, pelleting of the seed is commonly practiced. Pelleting of seed protects the inoculum from antibiotics present in seed coat. The most commonly used pelleting agents are calcium carbonate, rock phosphate, charcoal, talc, gypsum and bentonite. A good pellet should appear dry, should be firm enough and should withstand light rolling between the fingers.

MECHANISM OF BENEFICIAL EFFECTS THROUGH BIOFERTILIZERS

The mechanism by which the plants inoculated with biofertilizers derive positive benefits in terms of increased grain, plant biomass, N uptake and other benefits may be discussed under following heads:

- Increased nitrogen content and residual effect of legumes.
- Salt tolerance of rhizobial strains.
- Production of siderophores
- Presence of plasmids
- Production of growth promoting substances, enhanced assimilation of nitrogen and other nutrients by plants.
- Production of acids including organic, hydroxy acids and chelating materials.
- Beneficial effects on other organisms in rhizosphere.
- Production of antifungal antibiotics and fungistatic compounds
- Mechanism leading to other beneficial effects.

Increased nitrogen content and residual effect of legumes: Field performance of legumes and pulses is variable. Sometimes the yields are not increased but the N content of grain or biomass is increased over the inoculated control. The residual effects of leguminous crop over succeeding cereal crop ranges from 20 to 123 kg N /ha (Patra, 1987). Algal material undergoes decomposition and converts 10–15 % fixed nitrogen into polymers similar to humic acids. This indicates the residual effect of BGA on the subsequent crop. The biomass produced by algal fertilizers is useful for the reclamation of saline alkali and calcereous soils. This may be attributed to the large amount of organic matter produced by algal mass.

Salt tolerance of rhizobial strains: Salt tolerance of *Rhizobium* was always observed to be higher than that of the host plant. Yadav and Vyas (1973) observed that *Rhizobium* from different host infective group could grow in the pH range of 5.0 to 10.0. The wide range of salt and pH tolerance indicates the adaptability of the rhizobia under various ecological conditions.

Production of siderophores: Biofertilizers increase micronutrient supply such as iron through the production of siderophores. Siderophores are reported in Genus *Azospirillum*, *Cowpea rhizobia*, *R. meliloti* and *R. leguminosarum* (Wani, 1990).

Presence of plasmids: Presence of plasmids in strains of *Rhizobium leguminosarum* imparts resistance to high temperature or low moisture conditions. Survival of strains in soil can be improved by identification of plasmids carrying genes for resistance to environmental stresses and transferring them into high effective strains.

Production of growth promoting substances, enhanced assimilation of nitrogen and other nutrients by plants

- Field experiments conducted with *Azotobacter* showed that in the majority of experiments, sizable increase in crop yields were obtained (Shinde, 1987; Shinde and Apte, 1982). This is more due to production of growth promoting substances like gibberellins, indol acetic acid (IAA), B vitamins and antifungal substances. *Azotobacter* adds in nitrogen fixation and subsequent release of fixed nitrogen in forms available to plants. *Azotobacter* can excrete ammonia in the rhizosphere in presence of root exudates and improves nutrient uptake by the plant.
- *Azospirillum* biofertilizers enhance total nutrient assimilation of NPK. Bacterization through *Azospirillum* results in yield increases, which may be attributed to plant growth promoting substances, and enhances nitrogen assimilation by plants.

- The beneficial effects of phosphate solubilising bacteria are attributed to the production of growth promoting substances or fungiasts in the rhizosphere.
- Mycorrhizal association is of importance to plant nutrition, especially in nutrient deficient soils. Mycorrhizal fungi assimilate nutrients from soil for their own needs, and in addition, translocate them in different forms to the host roots. There is more efficient absorption of labile phosphorus by mycorrhizal plants.

Production of acids including organic, hydroxy acids and chelating materials: Micro-organisms play an important role in the mobilisation of soil phosphorus. Solubilisation of insoluble inorganic compounds is brought about by some of the species of *Bacillus*, *Pseudomonas*, *Mycobacterium*, *Micrococcus*, *Flavobacterium*, *Penicillium*, *Sclerotium* and *Aspergillus*.

Production of organic acids and simple phosphorus containing compounds: These bacteria and fungi (mentioned above) bring about solubilisation by the production of organic acids, aliphatic and aromatic acids, phytases, phospholipases etc. *Azotobacter* form biologically active substances like vitamins of the B group, nicotinic acid and pantothenic acid, biotin, heteroauxin and gibberellins.

Action of chemoautotrophs, ammonium and sulfur oxidizing bacteria: The chemoautotrophs, ammonia and sulfur oxidizing bacteria produce nitric and sulfuric acids, which converts tricalcium phosphate to di and mono basic phosphates leading to increased availability of phosphorus to the plants.

Production of hydroxy acids: The organic acids specifically hydroxy acids promote solution of the mineral, liberate hydrogen sulfide which reacts with the acids to yield ferrous sulfide liberating the phosphate.

Chelating effect of nutrients: Some of the hydroxy acids produced by phosphate solubilising bacteria may chelate Ca, Al, Fe and Mg resulting in effective availability of soil P and hence its greater utilization by plants.

Beneficial effects on other organisms in rhizosphere

- Mycorrhizal colonization also allows population of beneficial soil organisms like *Azotobacter*, *Azospirillum* and *Phosphate solubilising bacteria*.
- Forest trees like *Casuarina* and *Alums* are benefited from N₂ fixing symbiosis through an actinomycetous microsymbiant called *Frankia*.

Production of antifungal antibiotics and fungistatic compounds: *Azotobacter* has ability to produce anti-fungal antibiotics and fungistatic compounds against pathogens like *Fusarium*, *Alternaria* and *Trichoderma* (Brown, 1962; Mishustin and Shilnikova, 1972; Lakshmi-Kumari et. al., 1972).

Mechanisms leading to other beneficial effects

- *Azotobacter* has the ability to form pigments. Aged cultures of *Azotobacter chroococcum* form an insoluble black brown pigment commonly attributed to the presence of melanin. This melanin is formed as a result of oxidation of tyrosinase, a copper- containing enzyme (Tilak, 1993).
- *Azotobacter* improves the germination and vigour of young plants and leads to an improved stand in crops inoculated with *Azotobacter* cultures.
- Enhanced seed germination has been observed due to *Azotobacter* inoculation.

- The onset of flowering of wheat was also hastened by *Azotobacter* (Rovira, 1965).
- *Azotobacter* is also involved in the development and branching of roots, increased nitrate reductase activities and production of plant growth hormones.
- VAM inoculation improves water relations of the plants.

FACTORS AFFECTING EFFICIENCY OF BIOFERTILIZERS

It is essential, as a first step, to know the requirement of biofertilizers. Requirement of biofertilizers should be based on the active bacterial population per unit soil. It should also take into account the natural distribution of microorganisms. Requirements based on multiplication of total area by dosage may be of little practical utility since it may provide exaggerated estimates. Following factors in soil may influence efficiency of biofertilizers. The discussion includes important aspects of nitrogen fixation as well.

(i) C:N ratio, (ii) Rhizobial strain, (iii) Multiple inoculation, (iv) Micro-organisms in rhizosphere, (v) Organic matter, (vi) Temperature and moisture, (vii) Aeration, (viii) Sunlight and drying, (ix) Mineral nutrients, (x) Effect of pesticides on legume-*Rhizobium* symbiosis and nitrogen fixation and (xi) Other factors affecting nodulation and efficiency of biofertilizers.

Carbon Nitrogen Ratio

C: N ratio plays significant role in nodule formation. For example, the genus *Azotobacter* is highly versatile in utilizing carbon sources. Therefore application of organic carbon containing sources to the soil improves asymbiotic nitrogen fixation capacity of the diazotroph *chroococcum* is capable to solubilise inorganic phosphates in soil. In general plants which are sensitive to nodulation have high C: N ratio.

The organic soil constituents of simple utilizable carbon and mineralizable nitrogenous compounds are of immediate significance for bacterial activity. C: N ratio of organic material is important factor in the soil ecology of chemoheterotrophic nitrogen fixers. If the assimilable C: N ratio is high, the non-nitrogen fixers will exhaust nitrogen supply and cease growing, leaving adequate amounts of carbon compounds for the nitrogen fixers. Materials rich in carbohydrates with almost no nitrogen provide a favorable environment for *Azotobacter*. Environments with decomposing proteinaceous waste products like sewage are unfavorable for nitrogen fixing bacteria.

Rhizobial Strain

Inoculation with efficient *Rhizobium* strain specific to each crop is very essential for the N gains and better crops yields. The plant nodulated by ineffective rhizobial strain showed lower dry matter yield, grain yield and nitrogen content irrespective of the number of nodules. The association of nitrogen fixing bacteria with roots of cereals and grasses is well known. Inoculation with *Azotobacter* and *Azospirillum* benefit cereal fodder crops and pasture grass. *Rhizobium* inoculation (effective symbiosis) contributes to addition of nitrogen depending

upon the crops.

Host plant is the dominant factor in assessing the effective and ineffective strains of Rhizobia (Burton *et al.* 1954). It is now established that some strains of rhizobia are more acceptable than others to a particular host plant.

Azotobacter is a better inoculant for fodder crops. *Azospirillum* is a better nitrogen fixer for perennial crops and pasture grasses. *Azospirillum* is known to colonize the rhizosphere of the roots of a wide variety of plants. *Azospirillum lipoferum* is found in corn roots and *A. brasilense* in roots of wheat and rice. *Azospirillum* has been shown to be capable of penetrating roots of *Panicum maximum*. Knowledge of the specificity of association between *Azospirillum* and various grasses and cereals may have significant implications in establishing nitrogen-fixing associations with selected strains of bacteria. Nitrogen fixing bacteria can be isolated from surface sterilize rice roots if the roots are washed to release the bacteria. Important nitrogen fixing bacteria observed in the rhizosphere of grasses in India are listed in Table 23.6 Inoculation with *Rhizobium* to all-important legume fodder crops and on pasture legumes and shrubs studied over the years has been presented in Table 23.7

Multiple Inoculation

Multiple inoculations with suitable combination of bio-inoculants is likely to supply a number of nutrients. Twin inoculation of seed (of legume) both with the *Rhizobium* and VAM is more economical and more effective for a variety of crops.

(Table 23.8) Hazra (1994) reported that a combined application of $ZnSO_4$ @ 10 kg /ha and *Azotobacter* inoculation gave significant increases in forage yield of pearl millet than their sole application. Rock phosphates show increase efficacy with rhizobial inoculation in lucerne. It was observed that the association effect of B polymyxa H5, (phosphate solubilising bacteria) *Aspergillus awamoori* (phosphate solubilising fungi) *Rhizobium loti* LL 28-2 (a *Rhizobium* strain) VAM

Table 23.6. Important nitrogen fixing bacteria observed in the rhizosphere of grasses

Bacterium	Plant
<i>Azotobacter paspali</i>	<i>Paspalum notatum</i>
<i>Azotobacter</i> spp.	<i>Cynodon dactylon</i> , <i>Zea mays</i>
<i>Beijerinckia</i> spp.	<i>Cynodon dactylon</i>
	<i>Digitaria decumbens</i> , <i>Cyperus</i>
	And other forage grasses
<i>Derxia</i> sp.	Tropical grasses
<i>Azospirillum</i> sp.	Most tropical forage grasses including
	<i>Zea mays</i>
<i>Bacillus macerans</i>	<i>Agrostis tenuis</i> , <i>Festuca</i> sp.
<i>Enterobacter cloacae</i> and <i>E. aerogenes</i>	<i>Zea mays</i> , <i>Panicum maximum</i>
	<i>Juncus balticus</i> , <i>Agrostis tenuis</i> ,
	<i>Andropogon gerardii</i> , <i>Panicum virgatum</i>
<i>Klebsiella pneumoniae</i>	<i>Panicum maximum</i> , <i>Chloris divaricata</i>
<i>Clostridium</i>	<i>Digitaria smutzii</i>

Source: Sreekumar and Tilak (1988)

fungi were found to be more effective in terms of nodulation, herbage yield and nitrogen content than *Rhizobium* alone (Pahwa, 1990). Inoculant containing multistrains of *Rhizobium* (TAL-82, TAL-582 and LL-28-2) gave superior performance in terms of herbage yield and crude protein content than any of these pure strains. Inoculation of *Rhizobium* in presence of VAM was found to produce higher nodulation and forage yields than *Rhizobium* or VAM alone (Table 23.8). Inoculation with *Azotobacter chroococcum* alongwith *Rhizobium* did have added advantage in terms of forage yield and nitrogen content of the plants than pure *Rhizobium* inoculation. (Hazra, 1994) Dual inoculation of *Glomus* and *Rhizobium* results in efficient solubilisation of rock phosphate.

Micro-organisms in Rhizosphere

Interaction among micro-organisms is governed by several factors such as competition for nutrition inhibition or acceleration of growth by other organisms, exchange of matabolites etc. Organisms in the rhizosphere may either exert a beneficial effect on the growth of a particular organism or may inhibit the growth. Some leguminous plants produce inhibitory substance, which have toxic effect on the rhizobial proliferation in the rhizosphere. Rhizobia have the ability to multiply in the rhizosphere of non-legumes. Thus they are capable of surviving in soil in absence of leguminous plants.

There is a variation in the ability of rhizobial strains to endure antagonistic

Table 23.7. Effect of *Rhizobium* inoculation to some important forage legumes

Crops	Green forage yield(q/ha)		Per cent increase over control
	Without Inoculation	With Rhizobium inoculation	
Cultivated legumes			
Cowpea (<i>Vigna unguiculata</i>)	392	457	17
Rice bean (<i>Vigna umbellata</i>)	215	245	14
Cluster bean (<i>Cyamopsis tetragonoloba</i>)	257	285	11
Lablab bean (<i>Lablab perpureus</i>)	225	247	10
Berseem (<i>Trifolium alexandrinum</i>)	685	830	21
Persian clover (<i>T. respunatum</i>)	610	765	25
Lucerne (<i>Medicago sativa</i>)	592	757	28
Pea (<i>Pisum sativum</i>)	285	328	15
Indian clover (<i>Melilotus indica</i>)	237	272	15
Pasture, legumes and shrubs			
Stylo (<i>Stylosanthes hamata</i>)	360	455	26
Siratro (<i>Macroptilium atropurpureum</i>)	195	220	13
Butterfly pea (<i>Clitoria ternatea</i>)	317	415	31
Centro (<i>Centocema pubescens</i>)	228	285	25
Hedge Lucerne (<i>Desmanthus virgatus</i>)	235	269	14
Subabool (<i>Leucaena leucocephala</i>)	338	377	11
Shevri (<i>Sesbania sesban</i>)	325	363	12

Source: Hazra (1994)

Table 23.8. Effect of VAM inoculation on the yield of soybean (1990 and 1991)

Treatment	Percentage increase over control
Control	—
VAM Inoculation	5.2
Rhizobium inoculation	11.0
Combined application of Tr. 2 and 3	18.7
VAM + 30 kg P ₂ O ₅ /ha	20.6
VAM + 60 kg P ₂ O ₅ /ha	25.2

Source: Dubey and Gupta (1994)

microflora (Burton, 1964). A mixture of *Azotobacter chroococcum* and *A. brasilense* increased dry matter production of both maize and sorghum while inoculation with each bacterium alone did not significantly effect yield (Tilak *et al.* 1982). The aerobic spore-forming bacteria and the *Streptomyces* are the most active antagonists to the rhizobia (Allen and Allen, 1961). In general, the slow-growing rhizobia appear to be the most susceptible to the actionmycetes (Abdel-Ghafter and Allen, 1950).

Organic Matter

Several workers have reported that the presence of organic matter in soil had a favorable influence on the number of rhizobia. Organic matter influences the population of *Rhizobium* in the soil and thus enhances the chances of infection. It has been found that addition of farmyard manure enhances the number of nodules, the dry weight of nodules and the weight of the plant. Crop residue management increases the efficiency of biofertilizers. Crop residue management involves incorporation of straw (say wheat straw) in soil before sowing of crops. It provides energy to heterotrophs for microbial activity, which helps in slow release of nutrients as the decomposition proceeds. The increase in level of CO₂ increases nitrogen fixation by diazotrophs, direct absorption of CO₂ by plant roots and photosynthesis in plants. Dev and Tilak (1976) reported that farmyard manure proved better than organic cakes like neem-cake, mahua-cake and linseed/flax for the nodulation of legumes. Charcoal, activated vermiculite, phosphorus or potassium fertilizers are other materials used to increase the number of rhizobia.

Temperature and Moisture

The ability to tolerate elevated temperature is a desirable characteristic for any Rhizobial strain to be used in a tropical country like India. The temperature prevalent in the root zone influence nodule formation and nitrogen fixation and lot of variation exists in different strains of rhizobia and host species. Different temperatures may be needed for nodule formation and nitrogen fixation.

The distribution of nitrogen between roots and shoots is controlled by the effect of root temperature. Effective symbiosis is also hampered sometimes at higher temperatures (Burton, 1964).

Poor nodulation in field conditions may be attributed to low moisture and abnormal temperature, which affect the survival of *Rhizobia*. The thermotolerant strain of *Rhizobia* has been found to be superior in nodulation and nitrogen fixation

to other vigna rhizobial strain (not able to tolerate elevated temperatures).

Activity of nitrogenase is inhibited by moderate deficits of water by interfering with gaseous interchange between the soil and the nodule tissues. The presence of both aerobic and anaerobic soil zones can stimulate nitrogen-fixing capacity. This suggests a mutualistic relationship between *Azotobacter* and *Clostridium*. Under waterlogged soils, a proto-cooperative association between anaerobic photo-heterotrophic bacterium *Rhodopseudomonas* and aerobic chemoheterotrophic bacterium *Azotobacter* can develop. The phototrophic bacterial diazotrophs may become significant when proliferation of blue-green algae is somewhat inhibited.

Aeration

Nitrogen fixation in the legume nodule is an anaerobic process. The highest fixation usually occurs at 0.5 atmospheric oxygen. Nitrogenase activity is influenced by the concentration of dissolved oxygen in the solution. Higher levels of carbon-dioxide production from soils stimulate nitrogen fixation by direct effect on nodule activity (Mulder and Van Veen, 1960).

Sunlight and Drying

Cells of freshly inoculated culture do not withstand drying as much as the physiologically old cultures. However, Sen and Sen (1956) reported the survival of *Rhizobium* in stored soils up to 25 years. Light dependent nitrogen fixation can be observed with photosynthetic bacteria. These bacteria are dominant in the tropics. Nodulated legume requires illumination for nitrogen fixation (Virtanen *et al.* 1955). Some legumes show diurnal fluctuations in the level of nitrogenase activity in their nodules. This suggests a correlation between light intensity and nitrogenase activity. The stimulatory effect of increasing light intensity on symbiotic nitrogen fixation has been reported (Lie, 1974).

It has been observed that nitrogen fixation continues in nodules during normal periods of darkness. However, the level of difference as compared to illumination is variable (from no change to enhancement).

Mineral Nutrients

An appropriate and adequate nutrition is required for the effective functioning of the inoculants being used as biofertilizer. Addition of nutrients particularly micronutrients are useful in two ways: (i) Addition of nutrient help in plant nutrition and (ii) Nutrients interact with microbial strains in a beneficial way. Lack of nutrients does not cause rapid death of root nodule bacteria in soil. This is evidenced by the fact that incorporation of various nitrogen sources into soil resulted in no improvement in the survival of *Rhizobium* suggesting that rhizobial population be not restricted by the scarcity of nutrients.

Nitrogen : Lower doses of nitrogenous fertilizers increased the symbiosis and growth of the legume. Nitrate is less inhibitory to nitrogen fixation than to nodulation. Combined nitrogen may suppress the activity of nitrogenase. Addition of small amounts of starter nitrogen increases nitrogen fixation.

Phosphorus: Phosphorus requirement for nodule formation is much greater than that for nodulation (deMooy and Pesek, 1966). Application of phosphorus

increases nitrogen fixation in leguminous plants. Phosphorus has a important role in protein synthesis.

Calcium and magnesium: Calcium and magnesium are essential for the growth of rhizobial cell. Calcium is required for nodule formation as a component in cell-wall development. It also helps in counteracting soil acidity. Carbonates and hydroxides of calcium and magnesium neutralize the acidity, which increase rhizobial growth and survival. The total need of the rhizobia for calcium and magnesium ions has been found to be 20 times the specific requirement in respect of calcium ion and 5 times for magnesium (Vincent, 1977).

Aluminium: A higher concentration of Al in acid environment is unfavorable to rhizobia living in soil. Aluminium toxicity limits nodulation and nitrogen fixation more than plant growth.

Other elements: Low potassium availability limits the amount of nitrogen fixed by nodulated legumes. Deficiency of sulfur restricts nitrogenase synthesis. Boron is required for nitrogen fixation in nodulated legumes. Nodular nitrogen fixation has been found to be sensitive to manganese toxicity. Cobalt, iron, copper and zinc are also important for rhizobia. Molybdenum is important in the nutrition of *Rhizobium* and in the nitrogen fixing process.

Effect of Pesticides on Legume-Rhizobium Symbiosis and Nitrogen Fixation

Most of the insecticides when used at normal rates of application do not inhibit nitrification. As much as five times of the normal dose of aldrin and chlordane was found to be necessary to inhibit nitrification (Sinha, 1961). Variable effects and a great variation in the concentration of pesticides have been found to influence nodulation. 1–10 ppm levels of insecticides appeared to stimulate the pigment production. Application of Lindane above 5 ppm inhibited nodulation and grain yield of chickpea. Singh *et al.* (1977) observed that seed treatment with Dithane M-45 and Bavistin at the rate of 0.25% (W/W) markedly increased the nodulation and nitrogen fixation by pea. Herbicides in general do not have nitrification inhibitory property at normal rates of use. Large number of laboratory studies showed that chlorate, ammonium thiocyanate and sodium carbonate retarded nitrification in soil. Some effects of insecticides in soil on nodulation of different legumes are presented in Table 23.9

Other Factors Affecting Nodulation and Efficiency of Biofertilizers

Some soil conditions affect an abundant supply of effective root nodule bacteria for crops that are grown. Ineffective nodulation and quality of inoculant affect nodulation.

Soil conditions: Neutral to slightly acid conditions (pH 6.7–7.3) are generally optimum for most rhizobia. In acid soils the rhizobia do not survive (pH < 5.0). Rhizobia are killed when inoculated seed comes in contact with acid fertilizers at sowing. These hazards can be greatly reduced by adopting such precautions as lime pelleting, sowing with neutral fertilizers and band seeding so as to avoid direct contact between the rhizobia and the acid conditions (Tilak, 1993). While using a bio-inoculant in strongly acidic or saline-alkali soils, it would be desirable to use some soil amendment such as gypsum/phosphogypsum for saline alkali

Table 23.9. Effect of insecticides in soil on nodulation of legumes (Gaur, 1980)

No effect on nodulation	Reference
Carbaryl (2.8; 14;28) on soybean nodulation	Kapusta and Rouwenhorst(1973)
Dieldrin	Diatloff (1970)
Endrin	Swamiappan and Chandy (1975)
Disulfoton (1.7; 8.4; 16.8)	Kapusta and Rouwenhorst (1973)
Chlorfenvinphos (1.1 a.i.)	Swamiappan and Chandy (1975)
Trichlorfon	Salama <i>et al.</i> (1974)
<i>Increased nodulation</i>	
Lindane (2.2 g/kg-1 seed) in skeletal podzolic soil	Diatloff (1970)
Isobenzene (2") in lucerne	Salem <i>et al.</i> (1971)
Diazinon (80:120)	Salem <i>et. al.</i> , (1971)
Fonofos	Diatloff (1970)
<i>Decreased nodulation</i>	
DDT(0.5-100 a.i.) increased nitrogen fixation in alluvial soil	Pareek and Gaur (1969)
Phorate (1.1 a.i.)	Swamiappan and Chandy (1975)

soils and lime or rock phosphate for strongly acidic soil to maintain soil pH near neutrality (6.5 to 7.5).

Ineffective nodulation: It may result from the presence of a large native population of rhizobia. These organisms may compete with the rhizobia applied on the seed for nodule formation and makes it ineffective in fixing nitrogen with the introduced legume. The use of inoculants containing ineffective strains of rhizobia is another important factor. Measures should be adopted to avoid such situations by judging effective strains of rhizobia.

Quality of Inoculant

Poor quality inoculant or mishandling of inoculant may lead to low number of rhizobia in the culture. An insufficient number of rhizobia may cause failure of seedlings to become nodulated. The following precautions should be taken to obtain maximum efficiency from inoculant.

- The packet(s) of the culture should be placed in cool and shady place till their use. The material should be used before the date of expiry mentioned on the packet.
- Use the biofertilizers for the crop specified. The use of clover inoculant to inoculate lucerne seed will result in plant without nodules.
- Open the packet containing the culture just before use and inoculate that much seed, which could be sown immediately.
- Do not put the culture in hot water, which could destroy the living bacteria contained in the biofertilizer.
- For seed treatment, if besides a bio-inoculant, the seed is also to be treated with a fungicide or insecticide, treat the seed first with a fungicide followed by the insecticides and finally with the biofertilizer.

COMMERCIAL PRODUCTION OF BIOFERTILIZERS

Biofertilizers are not so popular as chemical fertilizers. This is because the crop response to biofertilizers is not as instant as has been possible with chemical or mineral fertilizers.

Availability of strains: Non availability of appropriate and efficient strains has been found to be one of the major constraints in widespread adoption of biofertilizer technology. Most of the biological strains of biofertilizers are soil and agro-climatic specific. Region wise inadequate availability of specific strains limits their popular use.

Biofertilizer carrier: Lack of suitable carrier, due to which their shelf life is short, is another constraint. Peat has been recognized as the most suitable and standard carrier. Peat is an ideal carrier material but it is not abundantly available in the country. Lignite and charcoal are used as a carrier material. Charcoal is used because it is readily available.

Maintaining quality of inoculant: Lack of qualified personnel engaged in the production, improper production facilities and lack of appropriate production technique result in poor quality inoculants. Besides production, poor transport distribution and storage facilities results in poor quality inoculants. For example, inoculant, which can be, stored for 6 months at 20°C, loose their effectiveness within a few hours at 40°C or higher temperature.

Marketing of biofertilizers: The demand and production of biofertilizers is seasonal. The marketing of biofertilizer is not easy as the product contains living organisms. The shelf life of biofertilizers produced by using peat or lignite as carriers is less than 6 months. The best results are possible if the material is used within 3 to 4 months. There exists a huge gap between the potential demand and actual supply of the material. Against a potential demand of one lakh ton per annum, the estimated total installed capacity for various biofertilizers in the country is 3000 tons and production is about 2000 tons.

Biological nature of biofertilizers: Biofertilizers release nutrients slowly as compared to mineral fertilizers. The yield responses are not immediate as in case of mineral or chemical fertilizers. Presence of antagonistic strains in the inoculant depresses the efficiency of biofertilizers. Field experiments with VAM are fewer. It is difficult to obtain pure inoculum of VAM. This is because VAM is an obligate symbiont and can be maintained and multiplied on live plants. Mutation, which arises during fermentation results in reduction in effectiveness of bioinoculants.

Soil conditions: Soil conditions such as acidity, alkalinity, pesticides application and high nitrate level limit the nitrogen fixing capacity of the inoculants resulting in poor performance results of inoculants. Presence of certain toxic elements and deficiency of P, Cu, Co and Mo is unfavorable for bacterial fertilizers.

Educational programs: A majority of farmers and extension workers are not aware about the potential of biofertilizers. Demand is limited because of poor knowledge about the usefulness of biofertilizers.

Cost of production: The low pricing structure and low offtake of biofertilizers do not permit the use of sophisticated facilities. Thus it is difficult to ensure the production of contamination free products.

Future Planning

In the last five to six years efforts for promotion of biofertilizers technology have been intensified by the Department of Agriculture and Cooperation and it is felt that if sustained efforts are applied, biofertilizers play a significant role in Indian agriculture. India has the largest area of crops where biofertilizer technology may be quite beneficial. Future research should consider following parameters to increase the efficiency of biofertilizers.

Increasing competitiveness in rhizosphere: Biological nature of biofertilizers and their susceptibility to biotic and abiotic factors is responsible for highly inconsistent performance. Establishment of any introduced microbe in the rhizosphere through biofertilizers application depends on the competitiveness of the strains. It needs further research.

Survey of native microbial strains of different ecological regions: It helps in establishing requirement of inoculum of the area.

Selection of efficient and competitive strains: The bacterial strains should be of desirable characteristics. The strains should perform well under adverse environmental conditions of varying temperature and moisture stress, pH changes, pathogen resistance etc.

- Identification of *Azolla* species: Heat or cold tolerant *Azolla* species needs to be identified. Its production and distribution needs to be initiated.
- Blue-green algae: Factor responsible for colonization and growth of inoculated algae should be studied.
- Identification of phosphate solubilising organisms: To identify areas and crops for which such inoculation likely to be more successful in increasing the availability of native and applied P fertilizers.
- Use of VAM as biofertilizers: There is a need to evolve suitable methods to multiply VAM on a large scale.
- *Azospirillum*-*Azotobacter* strains: To ascertain the efficient strains of *Azospirillum* and *Azotobacter* for promoting crop yields.

Suitable carriers for inoculants: Suitable carriers for different microbes to ensure long shelf life and effectiveness. Thus search for newer synthetic carrier material, which are uniform non-toxic, simple to use and can sustain large population of microorganisms for a longer time must be used. In tropics, agro industrial wastes may prove better alternatives provided that suitable antimicrobial agent checks proliferation of contaminants. Storage of carrier based inoculants has been found to be better when inoculants were prepared in a mixture of soil and charcoal or pressmud and charcoal.

Identification of areas: It is necessary to delineate the areas where biofertilizers could be effective. (Both under rainfed and irrigated conditions)

Physical and chemical factors and agronomic practices: The establishment of the inoculant strains in the rhizosphere is affected by physical and chemical factors. Also, agronomic practices that influence biological nitrogen fixation by the host plant should be identified. The role of moisture conservation and soil management strategies to provide favorable environment around the root zone needs evaluation.

References and Suggested Readings

- Abdel-Ghaffar, A.S. and Allen, O.N. (1950). Transactions of International Congress of Soil Science : 4th Congress, Amsterdam III 3:193.
- Allen, E.K. and Allen, O.N. (1958). Biological aspects of symbiotic nitrogen fixation. In: *Hand buch der Pflanzenphysiologie*. Rubland W., (Ed.) Vol-B. Springer – Verlag, Berlin, pp. 48–118.
- Biofertilizers (1990). Scientific Publishers, Jodhpur.
- Brown, M. (1962). Population of *Azotobacter* in rhizosphere, and effect of artificial inoculation. *Plant and Soil* **17** : 15.
- Burton, J.C. (1964). Proceedings of 194 Biology. Colloquium Oregon State Press. Corvallis pp. 107–134.
- Burton, J.C. (1967). Rhizobium culture and its use. pp. 1–33 In: *Microbial Technology* Peppler, J. (Ed.) Reinhold Pub. Corp., New York.
- Burton, J.C., Allen, O.N. and Berger, K.C. (1954). *Soil Sci. Soc. Am. Proc.* **18** : 156–9.
- Deley, J. and Russel, A. (1965). *Journal of General Microbiology* **41** : 85–91.
- Demoooy, C.J. and Pesek, J. (1966). *Agronomy Journal* **58** : 275–80.
- Dev, S.P. and Tilak, K.V.B.R. (1976). *Indian Journal of Agricultural Science* **46** : 252–6
- Dubey, S.K. and Gupta, R.K. (1994). *Khad Patrika* **35** : 33–38.
- Fertiliser News* (1994). *Agronomy, Special* **39** : pp.27.
- Gaur, A.C. (1980). *Indian Journal of Microbiology* **20** : 362–70.
- Hazra, C.R. (1994). *Fertiliser News* **39** : 43–53.
- Katyal, J.C., Venkateswarlu, B. and Das, S.K. (1994). *Fertiliser News* **39** : 27–32.
- Lakshmi Kumari, M., Singh, C.S. and Subba Rao, N.S. (1974). *Plant on Soil* **40** : 261–8.
- Lakshmi Kumari, M., Vijaya Lakshi, M and Subba Rao, N.S. (1972). Interaction between *Azotobacter* sp. and Fungi. I. *In vitro* studies with *Fusarium moniliforme* Sheld. *Phytopathogische Zeitscript* **75** : 27–30.
- Lie, T.A. and Mulder, E. (Eds) (1971). Biological nitrogen fixation in natural agricultural habitats. *Plant and Soil* (special volume).
- Lie, T.A. (1974). Environmental effects on nodulation and symbiotic nitrogen fixation. In: *Biology of Nitrogen Fixation*. A Quispel, (Ed.) North Holland Publ. Co., Amsterdam.
- Mishustin, E.N. and Shilinkova, V.K. (1972). Biological fixation of atmospheric nitrogen by free living bacteria. pp. 82–109. In: *Soil Biological, Review of Research*. UNESCO, Paris.
- Norris, D.O. and Date, R.A. (1976). *Legume bacteriology*. Commonwealth Bureau of Pasture and Field Crops. Bulletin No. 51, pp. 134 Commonwealth Agriculture Bureaux, England.
- Pahwa, M.R. (1990). *Indian Farming* **39** : 25–27.
- Patra, D.D. and Subbiah, B.V. (1987). *Current Science* **56** : 23.
- Rao, A.C.S. and Das, S.K. (1982). Soil fertility management and fertilizers use in drylands. In: *A Decade of Dry Land Agriculture Research in India, 1971–80*, AICRPDA, Hyderabad, pp. 120–139.
- Rovira, A.O. (1965). Effects of *Azotobacter*, *Bacillus* and *Clostridium* on the growth of wheat. pp. 193–200. In: *Plant – Microbe Relationships*.
- Czechoslovakia Academy of Sciences, Prague.
- Sen, A. and Sen, A.N. (1956). *Journal of Indian Society of Soil Sciences* **4** : 125.
- Shah, J.P. and Joshi, H.U. (1986). *Fertiliser News* **31** : 75–77.
- Shende, S.T. and Apte, R.G. (1982). 'Azotobacter inoculation as a remunerative input for agricultural crops'. *Proceedings of National Symposium on Biological Nitrogen Fixation*, New Delhi, India, pp. 532–43.
- Shende, S.T. (1987). Significance of *Azotobacter* inoculation for agricultural crops. pp.

- 38–45. In: *Organic Manures and Biofertilizers*. Division of Microbiology, IARI, New Delhi, India.
- Singh, H.P., Rathi, Y.P.S. and Tilak, K.V.B.R. (1977). Note on efficiency of fungicides on nodulation and nitrogen fixation by pea (*Pisum sativum*). *Pantnagar Journal of Research* **2** : 102–4.
- Singh, R.P. (1982). Dry land research in retrospect and focus in the seventies. In: *A Decade of a Dryland Agriculture Research in India, 1971–80*, pp. 1–16.
- Sinha, N.P. (1961). *Proceedings of Annual Convention of Sugar Technology Association of India*.
- Sreekumar, K.R. and Tilak, K.V.B.R. (1988). In pasture and forage crops research – A state of knowledge report, *3rd International Rangeland Conference*, New Delhi. pp.248–58.
- Subba Rao, N.S. (1993). *Biofertilizers in Agriculture and Industry*. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi.
- Subba Rao, N.S., Tilak, K.V.B.R., Laxmi-Kumari and Singh, C.S. (1980). *Indian Farming* **30** : 3–5.
- Tandon, H.L.S. (1991). *Fertiliser News* **36** : 69–79.
- Tilak, K.V.B.R. and Singh, G. (1994). Biofertilizers – Research gaps and future needs. *Fertiliser News* **39** : 11–18.
- Tilak, K.V.B.R. (1993). *Bacterial fertilizers*. ICAR, New Delhi.
- Tilak, K.V.B.R. (1993). In *Nitrogen, Soil, Physiology, Biochemistry, Microbiology and Genetics*, INSA, New Delhi, pp. 165–172.
- Tilak, K.V.B.R., Singh, C.S., Roy, N.K. and Subba Rao, N.S. (1982). *Soil Biology and Biochemistry* **14** : 417–18.
- Vankateswarlu, B. (1992). Performance of biofertilizers in drylands : A critical review and future research needs. *Indian Journal of dryland Agricultural Research*, Sovenier, CRIDA, Hyderabad, pp. 42–58.
- Venkataraman, G.S. and Tilak, K.V.B.R. (1990). Soil Fertility and Fertilizer Use, Vol. IV, IFFCO, New Delhi. 137–148.
- Verma, L.M. and Bhattacharyya, P. (1994). Production, distribution and promotion of biofertilizers, 132–147 chapter 08 of Tandon, H.L.S. (1994). *Fertilizers, Organic Manures, Recyclable Wastes and Biofertilizers*, FDCO, New Delhi.
- Verma, L.N. & Bhattacharyya, P. (1990). *Fertiliser News* **35** : 87–97.
- Vincant, J.M. (1970). Manual for practical study of the root nodule bacteria. *IBP Handbook* **5**, Blackwell Scientific Publishing Co., Oxford.
- Vincent, J.M. (1977). Rhizobium – General microbiology. In: *A Treatise on Dinitrogen Fixation Sec III*. Hardy R.W.F. and Silver W.S., (Eds.) pp. 277–366. John Wiley & Sons, New York.
- Virtanen, A.I., Moisio, T. & Burris, R.H. (1955). *Acta. Chem. Scand.* **9** : 184–186.
- Wani, S.P. & Lee, K.K. (1991). Role of biofertilizer in upland crop production In: *Fertilizer Organic Manures, Recyclable Wastes and Biofertilizers*. HLS Tandon (Ed.) FDCO, New Delhi 91–92.
- Wani, S.P. (1990). *Indian Journal of Microbiology* **30** : 363–93.
- Yadav, N.K. & Vyas, S.R. (1973). *Folia Microbiol* **18** : 242.

QUESTIONS

Q. 1. Fill in the blanks

- i) To each hectare of land there are about _____ tons of nitrogen available in atmosphere.

- ii) In general, the slow growing Rhizobia appear to be the most susceptible to the _____.
- iii) In waterlogged paddy soils _____ are important source of nitrogen.
- iv) _____ is a free living heterotrophic nitrogen fixing bacteria
- v) Bacteria _____ is commonly found in roots of cereals and grasses .
- vi) _____ is a water fern .
- vii) Infection and nodule formation are _____ specific phenomena.
- viii) Tryptophan produced in the roots of the legumes is converted into _____ by Rhizobia.
- ix) In rhizobium legume symbiosis, infection thread is composed of _____ and _____ substances.
- x) Effective nodules are visually _____ in color.
- xi) Algal material undergoes decomposition and converts fixed nitrogen into _____ similar to humic acids.
- xii) Presence of _____ in strains of *Rhizobium leguminosarum* imparts, resistance to high temperature and low moisture.

Answers

(i) 80,000 tonnes (ii) actinomycetes (iii) Blue green algae (iv) *Azotobacter* (v) *Azospirillum* (vi) *Azolla* (vii) host (viii) Indol acetic acid (ix) cellulose and hemicellulose (x) pink (xi) polymers (xii) plasmids.

Q. 2. Choose the correct answer

- i) The cross-inoculation grouping system is not perfect / perfect .
- ii) All the strains of *Rhizobium* are not equally effective / equally effective.
- iii) C- nodulins are protien nodulins / species specific nodulins.
- iv) Small, white and scattered nodules with yellow color of plants are termed as ineffective / effective.
- v) All the Rhizobial strains found in soils are not beneficial / beneficial.
- vi) *Azotobacter* / *Azospirillum* is capable of utilizing carbon sources in soil.
- vii) *Azolla* / *Azotobacter* can be utilized under stagnant water conditions like rice cultivation.

Answers

(i) not perfect (ii) are not equally effective (iii) protien nodulins (iv) ineffective (v) not beneficial (vi) *Azotobacter* (vii) *Azolla*.

Q. 3. Define the following

(i) Biofertilizer (ii) Inoculum (iii) Mycorrhiza (iv) Carrier materials for inoculants

Q. 4. Differentiate between the following

(i) Slow growing and Fast growing strains of Rhizobia (ii) Effective and Ineffective nodules (iii) *Azolla* and Blue green algae.

Q. 5. Write short notes on the following

(i) Nodulins (ii) Host specificity (iii) Isolation of *Rhizobium* (iv) Method of inoculation (v) Use of *Azolla* as a biofertilizer (vi) Frankia (vii) Requirement of biofertilizers.

Q. 6. Give comments on the following statements

- i) Rhizobia have been divided into two groups based on their growth habits.
- ii) Plants mutually susceptible to nodulation by a particular kind of Rhizobia constituted a cross-inoculation group.
- iii) The ability to tolerate elevated temperature is a desirable characteristic of a *Rhizobium* strain.
- iv) Rhizobia may survive in soil in absence of leguminous plants.
- v) Infection and nodule formation are host specific phenomena .
- vi) Strains showing equal efficiency under the laboratory conditions may show marked difference in their ability to nodulate under field conditions.
- vii) Effectiveness of inoculants is influenced by temperature at which they are stored.
- viii) The marketing of biofertilizers is not easy.
- ix) There is a variation in the ability of Rhizobial strains to endure antagonistic microflora.
- x) *Azospirillum* biofertilizers are suited to tropical conditions.
- xi) Inoculation with *Azotobacter* may reduce fertilizer nitrogen application
- xii) Field experiments with *Vesicular Arbuscular Mycorrhizae* (VAM) inoculation are fewer.
- xiii) Biofertilisers are required in smaller quantities.
- xiv) The biomass produced by algal fertilizers is useful for the reclamation of saline alkali and calcareous soils.

Q.7. Answer in short for the following

- i) Classify biofertilizers.
- ii) What is meant by cross inoculation group?
- iii) What is meant by quality of inoculant? What parameters are included in quality control of inoculants?
- iv) What qualities should a 'carrier material' possess?
- v) Enlist four important asymbiotic nitrogen-fixing bacteria
- vi) Enlist cultural and biochemical characteristics used to identify *Rhizobium* strains
- vii) What are the beneficial effects of *Azotobacter* inoculation?
- viii) Name important phosphate solubilising organisms
- ix) What is the mechanism in the solubilisation of insoluble and organic P sources?
- x) What is Azolla Anabena complex?
- xi) Enlist four common genera of blue green algae
- xii) What are the estimates of nitrogen equivalent potential of important biofertilizers as reported by Tondon (1991)
- xiii) How does the production of organic acids through microbial fertilizers is useful in improving the efficiency of biofertilizers

Q.8. Answer in detail for the following

- i) What is the significance of application of biofertilizers? Give few examples
- ii) Explain the infection mechanism in legumes
- iii) What are the major constraints in the commercial production of biofertilizers?
- iv) What are the future research needs in the field of biofertilizers?
- v) What is the composition of Azolla? What are the ideal conditions for growth and multiplication of Azolla. How is Azolla incorporated in soil?
- vi) What qualities should a carrier material possess? Enlist a few carrier materials, their suitability and limitations in the preparation of biofertilizers.
- vii) Explain the mechanism of beneficial effects of biofertilizers.

Q.9. Give diagrammatic view of the following: i. Preparation of Rhizobial culture.

Soil and Environment

SOIL AND ENVIRONMENTAL POLLUTION

POLLUTION is accumulation of any substance that makes the soil air or water less desirable for people's use. The contaminant may be simple substance such as soluble salts or toxic or poisonous substances. Pollution occurs when some part of the environment is made harmful or offensive to organisms, especially to humans. A pollutant is something that, degrades the quality of something else.

Pollution is a term used to describe the presence of any elemental, ionic or molecular species at a concentration which has been accidentally raised as a consequence of human activity. It may, pose a problem to human, animal or plant health. Its detection and quantification may require sensitive and selective methods of chemical analysis. People destroy land as they build on it, pollute waters and air with fumes, dump wastes and make water shortages. Pollution control to a large extent thus depends on their activities on land. The following problems may be recognized in the pretext of pollution. (i) Conversion of agriculture land to non-agricultural uses (ii) Soil erosion (iii) Increasing salinity (iv) Diminishing water supplies (v) Modern technology. Solution to these problems and judicious use of resources could protect land from pollution.

Conversion of agriculture land to non-agricultural uses: Population of India has reached the one billion marks in 2000 AD and is expected to be 1.5 billion by 2025 AD. The corresponding estimated foodgrain requirement is 240 and 325 million tonnes, respectively. With the current level of production of 186 million tonnes, the production has to increase at the rate of 7.3 million tonne/year compare to the average level of 3.1 million tonnes/year over the past 40 years. The only way to achieve the required higher level of production is to increase the productivity per unit area of land. Pollution has resulted due to increased human activities on land to meet their requirements.

Soil erosion: In India, out of total reported geographical area of 329 million ha, about 167 million ha (about 51% of total) are affected by serious water and wind erosion, erosion due to shifting cultivation, and erosion of cultivable wastelands. In an analysis, it was estimated that about 5,334 million tonnes (16.35 tonnes/ha) of soil is detached annually due to agriculture and associated activities alone (Gurmeh Singh and associates, 1990).

Increasing salinity: About 12 million-hectare of land in our country is affected by salinity or alkalinity problems. They are not being cultivated or only meager amount of production is obtained from such soils. Reclamation of such soils has been part of the 20-point programme of our nation.

Diminishing water supplies: Water is the most precious and commonly used

resource with limited availability. Agriculture sector is the greatest user of water as it accounts for 80% of total consumption. The total water resources of the world are estimated to be 1.36×10^8 million-hectare metre. Out of this, 97.2% is salty water and only 2.8% is fresh water. The surface water is about 2.2% and the remaining is the ground water. Out of 2.2% surface water, 2.15% is fresh water in glaciers and ice-caps and only 0.01% (1.36×10^4 m ha-m) is available in lakes and streams. At present, nearly 4/5 of all the water used in the world is obtained from surface water resources. About 15% of world's cropland is irrigated (Raghunath, 1983). It is estimated that in India the annual average rainfall is 112 cm. The annual rainfall of the country fluctuates from region to region both in space and time. Rainfall over the entire country during the monsoon is nearly 75% of the mean annual while during pre monsoon and post monsoon seasons, the country receives almost 10 to 11% of the mean annual value.

Modern technology: Modern technology has necessitated maximum exploitation of natural resources. Due to population explosion, natural resources, forests and steppe have been developed and exploited on an ever-growing scale. Enormous reservoirs, canals, cities and factories have been built- the consumer and investment goods industries have boomed. At the same time, however, new problems have arisen as a result of the growing systematic destruction of the environment. We continue to pollute the environment with enormous quantities of refuse, sewage, exhaust fumes and other waste gases and thus impair the quality of our lives.

SOURCES OF SOIL POLLUTION

The pollutants which commonly reach the soil are (i) Pesticides, (ii) Inorganic pollutants, (iii) Organic wastes, (iv) Salts, (v) Radionuclides and (vi) Acid rain

Pesticides

Pesticides are the chemicals being used to control harmful organisms in every sphere of life of modern man, since they have become essential tool in present day agriculture. Pesticides include insecticides, fungicides, herbicides, rodenticides and nematocides. All chemicals are harmful when their concentration are high enough even though they are beneficial at low concentration. An insecticide used to kill certain organisms is not regarded as a pollutant unless it also kills other organisms that we consider beneficial. It becomes pollutant if it harms beneficial soil organisms. Pesticides reach the soil even though they were applied to plants, animals or other places. An ideal pesticide should not cause a pollution problem because it could not harm anything but the organism it was used to control. Acceptable pesticides must have the following characteristics:

- They must be short lived in the environment. There should be no residues in the foodstuffs. They must not exist long enough to accumulate in the food chains. Ideally a pesticide should remain long enough to kill the target organism and then be decomposed to harmless degradation products. For example, 2,4-D is decomposed in soil within about one month whereas DDT can persist for several years. More persistent pesticides may kill non-target organisms.
- Pesticide must not be carcinogenic (the ability to cause cancer in animals), teratogenic (the substance that causes tissue deformation) or cause mutations

(a physical or health defect, inheritable gene change)

- Pesticide must be effective and safe to handle. It means that the chemical is retained on the sprays or treated area, must not move extensively in the air and safely handled by the applicator.
- The chemicals should be preferably of low cost, low corrosiveness and of low caustic nature. Most pesticides are very toxic and short lived.

Inorganic Pollutants

The maximum permissible concentrations of many chemicals in soil, air, water and food has been prescribed. The primary aim is to protect human and animal health. The hazardous elements may reach the soil through, (i) the elements in soil considered harmful-their concentrations differ in indigneous and sedimentary rocks, (ii) Soils also receive elements from active volcanoes and (iii) emissions of metals in to the environment from waste disposal and from industries. The hazardous inorganic pollutants include, arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc.

Organic Wastes

The domestic and industrial sewage sludges are the major source of toxic elements. It is necessary to ascertain the level of inorganic and organic chemicals in the sludge prior to its application to the cropland. Garbage and sewage effluents are the important organic wastes.

- *Garbage:* Municipal garbage after being composted is used to enhance crop production. City garbage contains a very high percentage of decomposable organic matter and could serve as a good composting material.

Sewage effluents: Sewage sludge is the solid by product of industrial wastewater treatment plants.

- Manure contains soluble salts to the extent of 10%. Heavy application of this manure to soils without periodic leaching could cause a salt hazard to plants. On the contrary, leaching salts to ground water may pollute ground waters.

Salts

All natural waters contain mineral substances called soluble salts. The salt concentration increases as water is evaporated or it flows on the surface. Salts hinder plant growth, speed corrosion of metals, impure drinking water. Management of salt with low cost is the best remedial measure.

Radionuclides

Radionuclides are radioactive substances containing unstable chemical isotopes of elements and give off radiation (alpha, beta, gamma and other rays) at some specific half-life rate. Radionuclides decay with time in contrast to stable isotopes. These are destructive to biological tissues and can cause cancer or mutations, in some cases.

Acid rain

Acid rain, consists of rainfall with dissolved acids ($\text{pH} < 5.7$) The major contributing acids are H_2SO_4 and HNO_3 . Acid rains dissolve carbonates and kill aquatic life. It increases toxicity of aluminum, which is toxic. The nitric acid in

Table 24.1. Atmospheric sources of soil acidification

Sulphuric acid	Main source: atmospheric oxidation of SO ₂ and reduced sulphur compounds
Nitric acid	Main source: atmospheric oxidation of oxides
of nitrogen (NO ₂ , NO, N ₂ O);	
Hydrochloric acid	A combustion product of coal.
Carbonic acid	Formed by CO ₂ dissolving in water.
Sulphur dioxide	Man's activity: coal burning (main source), burning of other fossil fuels, smelting of metal sulphides. Natural source: volcanoes.
Reduced sulphur compounds	H ₂ S, released on combustion of crude oil, sulphur mining and some industrial processes; a product of microbial reduction. Dimethyl sulphide (DMS), (CH ₃) ₂ S, dimethyl disulphide, (CH ₃ S) ₂ , and carbon disulphide, CS ₂ , products of reduction; DMS is of marine origin.
Oxides of nitrogen	Nitrous oxide, N ₂ O, and nitric oxide, NO, products of microbial reduction. Nitric oxide and nitrogen dioxide, products of combustion of fossil fuels.
Ammonia	Released from soils with pH > 7 and from organic manures; soil acidity caused by microbial oxidation to nitrate (nitrification).

the atmosphere comes from various oxides of nitrogen accumulated in the atmosphere. The main acid and acid forming chemicals listed in Table 24.1

Heavy Metals

The term heavy metals, refers to metals with a density greater than 5 or 6 g cms⁻³. They are hazardous metals. All foods and water contain metals and non-metals that at high concentration can become harmful. Of greatest concern, however, are emissions of metals into the environment as a result of man's activities. The concentrations in the earth's crust and soils of elements considered to be a hazard are given in Table 24.2

The heavy metals occur in solution as cations and are adsorbed by the negatively charged soil particles. They are held strongly as complexes on the surfaces of clay alumino silicates, hydrated oxides and humus. In general, adsorption increases with pH. Heavy metal pollution is serious because it can persist for many decades.

Accumulation of Heavy Metals in Plants

It is important to differentiate between heavy metal tolerant and non-tolerant plants and also the extent to which the elements are transported to different parts of plants. The mechanism of metal tolerance by plants may be explained as follows:

- Exclusion from the roots: It is due to the competitive effect of other cations like Ca⁺⁺ and Mg⁺⁺, and also the heavy metal cations.
- Immobilization in roots: In some plant species, there is restricted translocation of metals from roots to shoots. The metals are retained by cell walls in the roots.
- Biochemical immobilization: Plants accumulate large amounts of metals that

are phytotoxic e.g. nickel from complexes with organic acids which reduce their interference with metabolic processes. Animal and humans do not ingest metals that are retained by the cell walls of fibrous root. Most of the metals that are transported to the shoots accumulate in the leaves and thus provide protection against toxicity problems.

Harmful Effects of Heavy Metals on Plant Growth

(i) There is a marked reduction in the chlorophyll content and nitrogen fixation activity after treatment with heavy metals. (ii) The heavy metals also create problems in the nutrient utilization by plants. (iii) Certain heavy metals and nutrient metals show phytotoxic behavior over a certain limit and hinder microbial activity in soils.

Flyash Pollution

Flyash is one of the major solid waste products of coal based thermal power station and industries. Around 60 million tonnes of flyash are being produced as a waste every year from different thermal power plants in India. The continuous use of flyash may impart toxicity due to hyper accumulation of heavy metals in soil. (i) Recent investigations have highlighted the ability of earthworm *Eisenia foetida* to detoxify the toxic thermal power waste flyash and transform sisal pulp and other organic, which waste into valuable vermicompost. (ii) The availability of nutrient enhances on addition of flyash to the soil. The accumulation of heavy metals on repeated addition of flyash can be avoided by processing flyash through vermitechnology and thus prevents the hyper accumulation of these metals.

PESTICIDES THEIR KINDS AND REACTION IN SOIL

Pesticides are chemicals used to kill pest organisms. The persistence of some of the pesticides is given in Table 24.3. Persistence is the quality of the compound

Table 24.2. Average concentrations of some hazardous metals

Metal	Earth’s crust (µg g ⁻¹)	Rocks with highest concentration	Soils (µg g ⁻¹)	Soils (Kg ha ⁻¹)
As	1.5	Shales and clays	0.1–50	0.2–100
Cd	0.1	Shales and clays	0.01–2.4	0.02–4.8
Cr	100	Ultrabasic	5–1500	10–3000
Cu	50	Basic	2–250	4–500
Hg	0.05	Sandstone’s	0.01–0.3	0.02–0.6
Ni	80	Ultrabasic	2–1000	4–2000
Pb	14	Granite	2–300	4–600
Zn	75	Shales and clays	10–300	20–600

Amount of metal per hectare calculated for a soil depth of 15cm and a bulk density of 1.3.
Source: Adapted from Alloway, B.J. (Ed.) 1990. Heavy metals in soils, Blackie, Glasgow.

Table 24.3. Persistence of Pesticides

Pesticides	Months (95% disappearance)	Pesticides	Months (90% disappearance)
Aldrin	24	Altrazine	9
Heptachlor	8	Simazine	12
BHC	18	Fenuron	5
Parathion	3	Linuron	5
Phorate	3	2, 4-D	1
Carbaryl	3	Chlorambene	2
Disulfaton	4	Dalapone	1
Aldicarb	4		

Source: Gupta, 1998.

to retain its chemical identity and biological effectiveness for long periods. D.D.T. (dichlorodiphenyl-trichloroethane) was found to kill a wide range of insects. Use of D.D.T. is restricted because

- It has long half life (the time required for half of the material to decompose), in the environment (Table. 24.3)
- It is accumulated in animal fat.

2,4-D (2,4- dichlorophenoxy acetic acid) is an effective herbicide, killing broad-leaved weeds in cereal crops. The problems in use of pesticides have been due to (i) discharge from industrial plant (ii) erosion of soil carrying particles into surface waters and (iii) overuse of pesticides. Pesticides that can be decomposed readily are biodegradables whereas those that resist decomposition is called persistent.

Classification of Pesticides

Pesticides are classified according to the target group of pest organisms as follows:

(a) Insecticides (b) Fungicides (c) Herbicides (d) Rodenticides (e) Nematocides (f) Antibiotic fungicides

Insecticides: Insecticides are chemicals used to kill the insects. Insecticides belong to following three groups (Table 24.4)

Chlorinated hydrocarbons: They are chlorinated hydrocarbons with chloride groups on carbon atoms. Nearly all chlorinated hydrocarbons have long half-lives in the environment, are of low water solubility and are non-selective in their actions. Example – D.D.T. The low biodegradability, persistence and toxicity to birds and fish have restricted and eliminated the use of chlorinated hydrocarbons.

Organophosphates: These are generally biodegradable and thus less likely to build up in soils and water. They are relatively much more toxic to humans than chlorinated hydrocarbons. Thus, a great care is needed in their handling and application. (Table 24.5).

Carbamates: Carbamates are readily biodegradable and have low mammal toxicity. Thus they are more popular among environmentalists.

Fungicides: Fungicides are chemicals used to kill fungi, bacteria and viruses

Table 24.4. Classification of pesticides

Chemical group	Examples
<i>Insecticides</i>	
Chlorinated hydrocarbons	Aldrin, chlordane, heptachlor, DBCP
Organophosphates	Diazinon, disulfoton, parathion, malathion
Carbamates	Carbaryl, carbofuran, methomyl, aldicarb
<i>Fungicides</i>	
Benzimidazoles	Benomyl, thiabendazole
Thiocarbamates	Ferbam, maneb
Triazoles	Triadimefon, bittertanol
Others	Copper sulfate, chlorothalonil
<i>Herbicides</i>	
Phenoxyalkyl acids	2,4-D, 2,4-DB, 2,4,5-T, MCPA, MCPB
Traizines	Atrazine, simazine, propazine, cyanazine
Phenylureas	Diuron, linuron, fluometuron, bromacil
Aliphatic acids	Dalapon
Carbamates	Butylate, vernolate, thiobencarb
Nitrophenols	Dinoseb
Dinitroanilines	Trifluralin, benefin
Dipyridyls	Paraquat, diquate
Amides	Alachlor, propanil, metlachlor

to control diseases. Fungicides are applied to control field diseases of fruits and vegetables, to protect harvested fruits and vegetable from decay and rot, to prevent wood decay and to protect clothing from mildew. Certain fungicides are small molecules and highly volatile compounds having fumigant action.

Herbicides: Herbicides are used to kill weeds without harming the crop. Herbicides are generally biodegradable and have relatively low mammal toxicity.

Rodenticides: Rodenticides are the chemicals which damage small mammals especially rodents like rats, mice etc, which damage mans dwellings, stored products and cultivated crops. For example zinc phosphide, cumarins, warfarin, fumarin, bromadiorone etc.

Nematocides: Nematocides are the chemical, which kill the nematodes that live in soil plant and water. These chemicals are halogenated hydrocarbons, organophosphates isothiocyanates and organocarbamates.

Antibiotics: The antibiotic fungicides are the substances produced by micro-organisms, which destroy other micro-organisms such as Penicillin, Tetracycline and Chlorophenicol.

Reactions of Pesticides in Soils

Once the pesticides are present in soil they under go one or more of the following reactions: (1) Adsorption (2) Volatility (3) Leaching (4) Chemical reactions (5) Microbial metabolism (6) Plant absorption .

Adsorption

The retention of pesticides by soils is called pesticides adsorption. It decreases

Table 24.5. Persistence of organophosphorus and carbamate insecticides in soil

Insecticide	Persistence (Half-life)
Malathion, monochrotophos, methyl parathion, menazon, primophosmethyl, carbaryl	5–10 days
Tetrachlorofevinphos, phorate, aldicarb, carbofuran dicrotophos	10–20 days
Disulfoton cytolane	20–30 days
Chlorofevinphos, fensulfothion, chloropyriphos	30–40 days

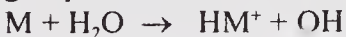
their concentration in solution. The degree of adsorption of pesticides depends on (i) their molecular mass (ii) tendency to form cations (iii) the presence of chemical groups. The process of adsorption takes place due to (i) the presence of functional groups such as $-\text{OH}$, $-\text{NH}_2$, $-\text{NHR}$, $-\text{CONH}_2$, $-\text{COOR}$ and $^+\text{NR}_3$ in the chemical structure encourages adsorption, especially on the soil humus.

- Hydrogen bonding
- Protonation [adding H^+ to a group such as $-\text{NH}_2$ (amino) group]

Humus and montmorillonite are most effective for adsorbing pesticides because they have large surface areas and high exchange capacities. Adsorbed pesticides are less active. Their low mobility reduces loss by leaching, adsorption by plants and decomposition by microbes. It indirectly controls water pollution by reducing leaching losses. Slower decomposition due to adsorption is because it is held so tightly that it becomes inaccessible to microorganisms.

The mechanism of pesticides adsorption could be explained as follows:

- Bonding by ion exchange: It depends on soil pH. For example, in the triazine group of herbicides, the molecule M becomes protonated at low pH.



The cation HM^+ is adsorbed onto negatively charged surfaces of clays and organic matter.

- Physical bonding, the large unchanged molecules are held by weak attractive forces.
- Hydrogen bonding, for example $-\text{NH}$ group the H atom acting as a bridge with an O atom on clay surface or an O atom in the carboxyl groups present in soil organic matter.
- Coordination bonding- It involves a sharing of electrons between the pesticides and mineral or organic surfaces.

Water-soluble pesticides can escape adsorption by being washed away into ground water.

Volatility

Pesticides have a wide range of volatility. Many pesticides are volatile. They diffuse through the soil. The diffusion helps to distribute them through soil and helps them escape to the atmosphere. Soil sterilizing agent ethylene dibromide diffuses through soil as a vapor whereas simazine diffuses in the liquid phase. A few herbicides (trifluralin) and fungicides (PCNB) are sufficiently volatile to make vaporization a primary means of their loss from soil.

Leaching

Conditions that encourage adsorption will discourage leaching. In general, herbicides are more mobile than fungicides or insecticides. Extensive use of herbicides has resulted in ground water pollution.

Chemical Reactions

Some types of pesticides are subject to photodecomposition when exposed to sunlight. Most pesticides are decomposed by sunlight at the soil surface (photolysis). For example DDT, diaquat and triazines are subject to slow photo decomposition of pesticides through hydrolysis, reduction and oxidation results in the degradation of fertilizers. For example, the triazine pesticides (atrazine) and organophosphate insecticides (malathion) are subject to hydrolysis and subsequent degradation in the soil.

Microbial metabolism

Micro-organisms carry out decomposition of pesticides. The microbial population and activity is controlled by factors such as energy supply, pH, and temperature. When the microbes are present, they need an energy supply and nutrients to make them active. The action of decomposable plant residues accelerates decomposition of pesticides. Aeration has a great effect on the decomposition rates of some pesticides (aerobic and anaerobic microbes decompose different materials). For example, 2,4-D is rapidly degraded under aerobic conditions at varying depths from 15 to 90cms. Atrazine degradation is slower and influenced more by depth. The phyto-toxicity of atrazine vanishes in 5 months at a depth of 15cms and in 17 months at a depth of 40cms but still remained after 41months at a depth of 90cms.

Microbial activity is normally faster at a pH near neutral than under very acid or alkaline conditions. For example degradation of 2,4-D was fastest when the pH was between 7.0 and 7.4.

Plant Adsorption

Higher plants generally absorb pesticides. The absorbed chemicals may remain intact inside the plant or they may be degraded. The degraded products may be harmless or toxic, and in some cases even more toxic than the original pesticides. Pesticide residues found in the edible portion of plants are of concern to humans.

Effect of Pesticides on Soil Organisms

The pesticides range from those of low toxicity to animals (many herbicides) to those that are very toxic to animals (some of the organic phosphates). Most pesticides are short-lived but extremely toxic, although some herbicides may remain active in the soil for more than a year (triazines). Most pesticides do not kill a broad spectrum of soil organisms. A few examples are presented below:

- Fumigation is done for control of nematocides, but it remarkably reduces soil flora and fauna. Also the population of bacteria increases after fumigation than before. This is due to the absence of competitors and predators following

fumigation.

- The effect of pesticides varies from organism to organism. For example, fumigation is needed for effective control of nematodes; organo phosphates are effective for control of mites. Most of the carbamates are toxic to earthworms.
- The concentrations of pesticides in the bodies of the earthworms are closely related to their population in the soil.
- Insecticides and fungicides may adversely affect the organism responsible for nitrification and nitrogen fixation. Recent evidence suggests that some pesticides can enhance biological nitrogen fixation by reducing the activity of protozoa and other organisms that are competitors of the nitrogen-fixing bacteria.
- Fungicides can have an adverse effect on soil fungi and actinomycetes thereby slowing down the decomposition of organic matter.
- The process of ammonification is often benefited by pesticide use.

The negative effects of most pesticides on soil micro-organisms are temporary and after a few days or weeks, organisms number generally recover.

TOXIC COMPOUNDS-HAZARDS OF CHEMICALS

There are many sources for the inorganic chemical contaminants that can accumulate in soils. The hazardous elements cover a wide range of chemical properties and react with soils in many ways. They include cadmium lead, zinc, fluorine, arsenic, mercury, boron, copper, nickel, chromium molybdenum and manganese. They can be categorized as follows:

Extremely poisonous	Moderate in toxicity	Low in toxicity
Cadmium	Lead	boron /
Arsenic	Nickel	copper
Chromium	Molybdenum	manganese
Mercury	Fluorine	zinc

Cadmium

Sources of accumulation

- It is present in zinc sulfide ores, zinc carbonates and silicates, lead and copper sulfides. Cadmium is used as electroplating pigments for plastics and paints, plastic stabilizers and batteries. This causes environmental pollution.
- Cadmium is added through phosphate fertilizers, which contain on average 7ug Cd g⁻¹.
- Sewage sludge is a rich source of cadmium.

Cadmium in soil and plant

- In aqueous solution, cadmium is weakly hydrolyzed and the predominant ion is Cd²⁺
- It is adsorbed on to clay minerals including iron, aluminum and manganese

oxides, CaCO_3 , organic matter.

- Cadmium is mobile and can become a hazard if washed into domestic water supplies.
- Uptake of cadmium by plants is greatest from soils high in cadmium. Liming can decrease it.
- Much of the cadmium that enters the plant is retained in the roots. Cadmium translocated to the shoots is present in greater concentration in the leaves than in fruits or seeds.

Hazard to human health

High concentration of cadmium in rice caused poisoning of human beings in Japan in 1950s (a disease called itai-itai which killed several persons).

Lead

Sources of accumulation

- Lead is a toxic heavy metal. Its concentration in the earth's crust is relatively low. It is present in zinc sulfide ores, the carbonates and silicates and in lead and copper sulfides.
- The main source of soil lead is automobile exhaust from cars using leaded gas. Absorption of lead by garden crops eaten by man is another source
- Increasing use of lead in batteries, alloys and pigments, polyvinyl plastics, in electroplating metals affects environment.

Lead in soil and plant

- It occurs as PbO_2 in soil. Most of the lead occurs in soil as insoluble carbonates and sulfides and in combination with iron, aluminum and manganese oxides.
- Lead reacts with organic matter to form a complex of low solubility
- Lead is concentrated near the soil surface, moving very little down the profile.
- As it occurs as complexes in soil, lead is largely unavailable to plants.
- Addition of lead salts to soils or nutrient solutions produce only small increase in uptake, and most of this is retained in the roots.

Hazard to Human Health

Lead is often deposited on leafy vegetables and is easily removed by washing. It primarily affects children, cause permanent damage, behavioral problems. In 1984, the Environmental Protection Agency (EPA) estimated that 1.5 million children in the United States had enough lead in their blood to lower intelligence.

Zinc

Sources of accumulation

- Zinc differs from cadmium and lead, being an essential micro-nutrient for plants and animals, including humans.
- Zinc is the most abundant heavy metal. The principal sources are mining and smelting of zinc ores, the application of sewage sludge, sites beneath galvanized wire netting and electric cables.

Zinc in soil and plant

- High amounts of zinc in soil may lead to high uptake and the concentration can exceed 500 mg Zn g^{-1} plant dry matter (toxic level).

- Zinc form complexes with organic matter (less stable than cadmium and lead). Much of the zinc is strongly adsorbed as $Zn(OH)^+$ on to iron and manganese oxides and clay aluminosilicates.
- At high concentration in soil zinc can be phytotoxic, reducing the growth of plants. The principal hazard with zinc is therefore with plants.
- Plants that retain zinc in their roots have been found to be more tolerant of high concentrations in the soil than those, which transfer a high proportion to the shoots.

Hazard to human health

Excessive accumulation of zinc in human blood can cause problems.

Fluorine

Sources of accumulation

- Industries like aluminum smelter, cement and brick kilns, phosphate fertilizer factories emit fluorine compounds to the atmosphere
- They harm animals grazing on affected pastures.

Fluorine in soil and plant

- Fluoride ions (F^-) form complexes with aluminum in solution and on the surfaces of clay minerals and hydrated aluminum oxide.
- Fluoride ion is strongly held by the mineral surfaces. It forms calcium fluoride, calcium fluorapatite both having low solubility.
- Fluorine uptake by plants is not significantly increased due to presence of fluorine in atmosphere or fertilizers.

Hazards to human health

Fluorine appears in drinking water for animals and in fluoride fumes from industrial processes. Excess of fluorine in drinking water causes dental and skeletal problems.

Arsenic

Sources of accumulation: Arsenic may be accumulated due to continuous application of arsenic containing pesticides.

Arsenic in soil and plants: (i) Arsenic is present in soil in anionic form ($H_2AsO_4^-$) Hydrous iron and aluminum oxides adsorb this. (ii) Long term additions of arsenic sprays can lead to toxicity for sensitive plants.

Mercury

Source of accumulation: In swampy areas and lake beds toxic levels of mercury are found which are harmful to certain species of fish.

Mercury in soil and plant: Insoluble forms of mercury are converted to a soluble inorganic form called methyl mercury.

Hazards to human health: Methyl mercury is soluble and available for plant and animal absorption. It accumulates in some fish to levels that may be toxic to humans.

Boron

Sources of accumulation: Boron can be accumulated from irrigation water

high in boron or through fertilizers.

Boron in soil and plant: (i) Boron is relatively soluble in soil and toxic quantities are leachable, especially from acid sandy soil. (ii) Boron toxicity is usually considered a localized problem.

Copper

Source of accumulation: Copper is accumulated through mine tailings, fly ash, fertilizers, wind blown copper containing dust.

Copper in soil and plant: Being an essential micro-nutrient, its toxicity is not a problem except those conditions where sewage sludge is applied. Long term applications of copper fertilizers or fungicides containing copper may cause toxicity.

Nickel

Chromium and radioactive materials may be of environmental concern being gasoline additives used in alloy manufacture, electroplating and batteries. Chromium is used for electroplating, is a plastic stabilizer and is used in batteries. Radioactive materials like Uranium, Thorium and Rubidium are found in P fertilizers. The potential problems that this may cause are currently unknown. These inorganic chemical contaminants accumulate in soils. Their release into the atmosphere can be carried to long distances and later deposited on the vegetation and soil.

ORGANIC CHEMICAL CONTAMINATION, THEIR PREVENTION

The extensive use of poisonous organic chemicals such as pesticides for controlling various pests, pest borne diseases for getting higher yield, has aroused a concern of pollution hazards in agriculture.

Soil contamination by toxic elements can be reduced or prevented by (i) reducing soil application of materials containing toxic elements and (ii) reducing recycling of the toxicants.

- Reducing soil application of materials containing toxic elements: The soils are damaged by way of contamination by toxicants, through additions of different waters, processing plants, municipal refuse, use of pesticides etc. Thus there is a need for judicious use of pesticides, fertilizers, irrigation water, solid wastes, integrated nutrient and pest management for a substantial production.
- Reducing recycling of toxicants: This can be achieved through soil and crop management. The uptake of contaminated materials through plants should be minimized. Breaking the cycles of soil plant animal through which the toxicants accumulate may do this. This may be achieved as follows:
 - The soil may immobilize the toxins through incorporation of organic and inorganic soil amendments. farmyard manure, gypsum and pyrite have been used successfully.
 - Selection of crops and varieties that do not accumulate the toxicant in their vegetative as well as reproductive parts is beneficial.

- Introduction of some tolerant genotypes of crops which can give better performance in the polluted environment.
- The productivity of the land can be restored through identification of nature and extent of pollution.
- The level of toxicants being discharged from factories should be kept within the permissible limit prescribed for the industrial effluent.
- The storage for the sludge of effluent treatment plant should be perfect. It should avoid seepage or overflow.

WATER POLLUTION – FERTILIZER CONTAMINATION OF WATER, SOIL SALINITY

The pollution of ground and surface waters is of great concern. Fertilizer application can contribute to the pollution by providing a source of NO_3^- to ground water and N and P in various groups to surface waters.

Pollution through Water

- Water is indeed a wonderful chemical, which has unique properties of dissolving and transporting in suspension huge varieties of chemicals, and thus it can be contaminated very easily.
- In addition to surface water, ground water also contributes pollutants to soil when the latter is used for irrigation purpose and accumulates in the plants grown on such soils as their toxic amounts.
- Precipitation or rainfall sometimes encourages water pollution.
- Application of water containing higher concentration of toxic elements (heavy metals like Cu, Zn, Pb, Cd and Ni) results into enrichment of the topsoil with these toxicants. The requirement of some of these elements to the plants is very less or not at all and when their supply is adequate, they may become toxic and cause an adverse effect on plant growth. When these metals enter into the food chain would cause health hazards to the animal and human being.
- Higher concentration of nitrates in drinking water contaminated with bacteria cause blue baby disease (methaemoglobinemia) in infants and babies. Nitrate reducing bacteria in such cases have been found in gut and secretion of gastric juice having pH more than 4.0. Nitrate has been linked as higher risk factor causing various kinds of cancer in older persons. This is due to formation of nitrosamines in the digestive tract.

Pollution through Fertilizer

- Nitrates and phosphates are the chemicals most often involved. Nitrate contamination can occur in both surface runoff and drainage waters, while excessive levels of phosphates generally occur only in surface runoff.
- Fertilizers used to increase the growth of crops also increases algal growth in surface water. This is called Eutrophication. This unwanted growth leads to accumulation of dead organic material. Since decomposition of such materials uses oxygen, non-aerobic conditions develop. When the algae and plants die toxins can be produced. This decreases fish population in bottom water. Thus

quality of water is deteriorated from the point of the view of its drinking, recreational and aesthetic value and fishing potential. Eutrophication also increases the necessity to treat water for domestic use.

- Nitrate levels in drinking water above 10mg per litre, are considered a human health hazard.
- The fertilizer should be mixed with at least some soil, especially where conservation tillage practices are employed, to reduce surface runoff of the fertilizer compounds.
- Fertilizer N and P can be transported into waterways by surface runoff, subsurface drainage and groundwater inflow by:
 - Fertilizer particles can be directly washed off from soil surface.
 - Fertilizer nutrients released into solution can be transported as in surface runoff or leached into soil.
 - Fertilizer nutrients adsorbed on soil particles can be transported in dissolved forms in runoff.
 - Fertilizer nutrients can be recycled via the decomposing plant material into surface, sub-surface or ground water.

Runoff water have both dissolved and particulate N, but particulate organic N is the main form reflecting the high amounts of organic N in the soil. Most of the N is in the form of NO_3^- due to its high solubility and low retention in the soil. Phosphorus enters waterways mainly by runoff. Phosphorus is strongly adsorbed by the soil hence it usually remains in the topsoil.

Pollution through Soil Salinity

- Contamination of soil with salts is one form of soil pollution primarily agricultural in origin. Salts accumulate in soils because more salts move into the plant-rooting zone than move out. This may be due to application of salt-laden irrigation waters or irrigating poorly drained soils may cause it.
- Salts move up from the lower horizons and concentrate in the surface soil layers.
- Some sewage sludge has sufficiently high levels of salts to cause crop plant damage when the sludge is applied.

The control of salinity depends almost entirely on the quality and management of water. In some areas, removal of excess water by the installation of good drainage systems is required. In local areas sulfur or gypsum application can be used to eliminate sodium bicarbonate. Water quality is determined by appropriate public policies and by individual farm management such as which assures good soil drainage and optimum irrigation practices. Soils with high levels of fertility generally lose more nutrients by leaching the soils with low fertility levels. Some of the nutrient ions are absorbed and used by the plants and thereby protected against leaching. The growing plants transpire large amounts of water and thereby reduce the amount lost by percolation.

ATMOSPHERIC POLLUTION

Ozone Shield

Ozone shield is a concentration of ozone gas (O_3) in the upper atmosphere,

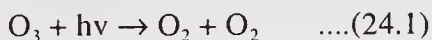
which reacts with and reduces much of the harmful ultraviolet radiation from the sun that reaches the earth. Actually the UV rays from the ozone split O_2 molecules into active O atoms. These active atoms recombine with O_2 molecules to form ozone (O_3). This process is in equilibrium between ozone destruction and formation.

The Atmosphere

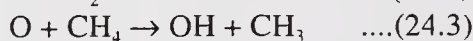
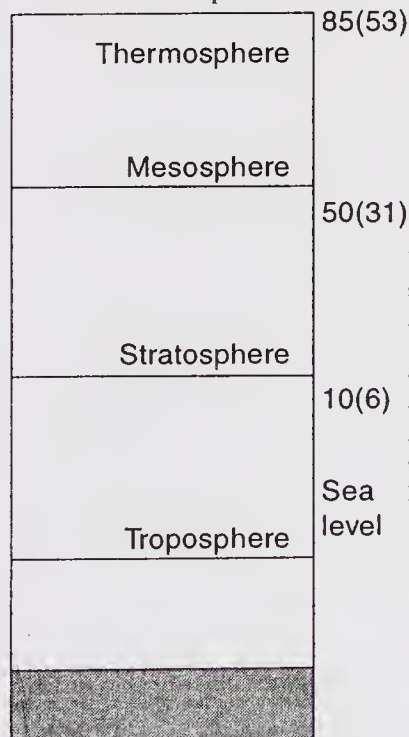
The main gases in the atmosphere are nitrogen (78.1%) and oxygen (20.9%). The remaining 1% is made up of inert gases, CO_2 , water vapor and the gases. The total mass of the atmosphere is about 5×10^{18} kg. Atmosphere, is a blanket of air that keeps the planet comfortably warm. Apart from providing air for living plants and creatures, the atmosphere acts as an insulator. The atmosphere has several layers. The lowest, known as the troposphere, varies in thickness from 8 km high in the north and south poles to twice that height at the equator. It holds 80 % of atmosphere's weight. Above the troposphere are the stratosphere, mesosphere and thermosphere.

The mixing ratio of the main gases nitrogen and oxygen are roughly the same throughout the atmosphere but the density decreases exponentially from the earth's surface (Fig 24.1).

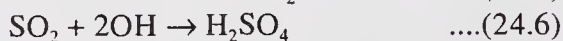
The atmosphere-chemical properties. Ozone (O_3) absorbs energy in the ultraviolet (UV) region of the spectrum and dissociates:



Where $h\nu$ is the energy of one photon and the electrons in the products are in an excited state. Because of their high energy level, excited oxygen atoms initiate several processes:



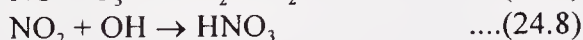
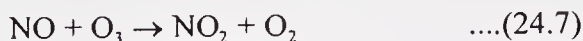
During daytime in the troposphere OH oxidizes several gases emitted from the earth's surface. For example:



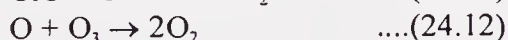
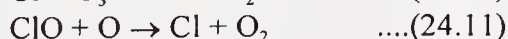
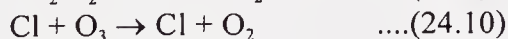
Nitric oxide is first oxidized to NO_2 and then to HNO_3 (24.7 nad 24.8). An important reaction of NO_2 in the troposphere is with the peroxyacetyl radical, $CH_3CO.O_2$, which is formed during the incomplete oxidation of hydrocarbons. The product is per oxyacetyl nitrate, known as PAN. Ozone and PAN are the irritants in smog; they can cause health problems. Gases like N_2O , chlorofluorocarbon compounds (CFCs) and CH_4 , diffuse into the stratosphere where they react with ozone. These reactions are

Fig. 24.1. Earth's Atmosphere

complex. For example the nitric oxide formed from nitrous oxide is oxidized further, leading to the destruction of ozone:



CFCs, lead to the destruction of ozone, for example CFC 12 is partly decomposed by photons in the stratosphere:



Most of the atmospheric ozone is found in the stratosphere. It absorbs nearly all the UV from the sun (wavelength 0.2 to 0.3 μm). These wavelengths are harmful to all living cells and may cause skin cancers. For these reasons destruction of stratospheric ozone is of great concern.

Factors Affecting Atmospheric Pollution

Following sources contribute to atmospheric pollution:

- Wind erosion: Dust particles are added by wind erosion, tillage practices, burning of fuels and residues
- Pesticides: Volatile pesticides are carried to great distances by wind
- Burning of fuels: It results in liberation of oxides of nitrogen and sulfur in the atmosphere.
- Decomposition of organic materials: Gases like ammonia, methane and sulfur oxides are produced through the anaerobic decomposition of organic materials.
- Recent research has shown that a high concentration of chlorine and related compounds reduced the concentration of ozone and creates ozone hole in the stratosphere.
- Denitrification: The biochemical reduction of nitrates or nitrites to gaseous form of nitrogen either as molecular dinitrogen (N_2) or as an oxide of nitrogen (N_2O). Oxides of nitrogen are linked with significant catalytic reduction of ozone in the stratosphere.
- N_2O emissions constitute significant proportions when nitrate containing fertilizers are applied on acidic soils. It has been found that atmospheric burden of N_2O has been increasing at the rate of 0.2% per annum. N_2O alongwith chlorofluorocarbons (CFCs) accumulated in the stratosphere will deplete ozones. Consequently, the effectiveness of the ozone layer as a protective shield for the earth against UV radiation will decrease.

The main concern of atmospheric pollution is related to ozone shield. A reduction in the ozone shield in the atmosphere is a consequence of pollution. Through release of gases like N_2O , CO_2 , CH_4 , CFC (Chlorofluorocarbon) attracted the attention of mankind throughout the world. Chlorine gas atoms, CCl_4 , NO also destroy ozone.

Use of Biotrickling Filter (Air Treatment System)

Microbes treat hazardous air emissions. This is an air treatment system fabricated by a small American company. The efficient, affordable system relies on the action of naturally occurring micro-organisms to metabolize air pollutants into harmless by-products. The microbes grow as a bio-film on synthetic packing material contained in a tall column that resembles a ship's smoke stack. Untreated air enters the column at the top and flows downward through the packing material along with re-circulating water. The microbes degrade and destroy the contaminants as they pass over the bio-film. The re-circulating water allows for optimal control of pH, nutrient levels, and bio-film thickness.

Known as a bio-trickling filter, this treatment method safely and efficiently destroys volatile organic compounds hazardous air pollutants and odour causing chemicals. Bio-trickling filters offer more cost-effective treatment options than standard bio-filters for compounds with low-water solubilities or slow degradation rates. The technology also is an effective treatment option for many biodegradable chlorinated compounds.

EFFECT OF AGRICULTURAL PRACTICES ON ENVIRONMENT

All human activities including cultivation or agricultural practices cause pollution. Most of the pollution has occurred when fertilizers have been applied inappropriately, particularly when applied at rates, which are in excess of plant requirements.

Use of Fertilizers

- Imbalance use of inorganic fertilizers can lead to soil degradation and a decline in soil productivity. The fertilizer use pattern in Asia has resulted in a depletion of soil fertility.
- There is an increase in the concentration of N_2O , CO_2 , and CH_4 in the atmosphere with an increase in the use of fertilizer in agriculture.
- Use of nitrogenous fertilizers has potential of increasing nitrous oxide emissions besides charging water with nitrates.
- Nitrogenous fertilizers may immobilize in the soil through microbes and/or higher plants. They may volatilize as ammonia and escape into atmosphere as N_2O through denitrification and leaches to ground water as nitrate or nitrite.
- The backdeposition of volatilization losses of ammonia on earth's surface induces acidification of soil.
- Ammonia in the atmosphere reacts with sulfates and/or oxides of sulfur (liberated mostly from factories) to yield ammonium sulfate which after deposition on earth's surface converts to acids as shown below:

$$(NH_4)_2 SO_4 + 4O_2 \rightarrow 2HNO_3 + H_2SO_4 + 2H_2O$$
- Phosphate fertilizers contain a high cadmium content and may cause environmental pollution. Katyal (1989) reported that the cadmium contents of phosphate rocks varied from 15 to 280 mg Cd per Kg P_2O_5 . In general, phosphate fertilizers contained high cadmium impurities. Application of these fertilizers increase build up in soil and utilization by crops (Table 24.6).
- Excess of potassium in grassland accompanied with higher applications of

Table 24.6. Lead and cadmium content of fertilizers

Fertilizer	Lead (ppm)		Cadmium (ppm)
	Arora <i>et al.</i> (1975)	Singh (1976)	Singh (1976)
Calcium ammonium nitrate	116	200	6
Urea	-	4	1
Single superphosphate	487	6098	187
Rock phosphate	962	1135	303
Muriate of potash	117	88	14
Diammonium phosphate	195	188	109
Suphala nitrophosphate	285	313	89

nitrogen may lead to grass tetany (hypomagnesemia) in cattle. Addition of salts through lateral seepage flow and those carried from field results in soil pollution.

Management of Soil Fertility

The soil fertility management practices of modern intensive high yielding systems are harmful to the soil environment. The farming systems should be such that results in a gradual build up of soil fertility.

Use of organic wastes

- The organic waste exerts beneficial physical effects on soil and is also the sources of plant nutrients.
- They also carry significant quantities of inorganic as well as organic chemicals leading to environmental degradation.
- The direct use of sewage sludge, industrial wastes and wastes water to agricultural land as a sources of plant nutrients is a serious concern as they contain many toxic metals along with plant nutrient element.
- Recycling of wastewater for irrigation purpose serve as an additional source of liquid fertilizer providing all the macro and micronutrients and elements needed for growing crops.

ENVIRONMENTAL DEGRADATION AND ITS MANAGEMENT

The causes of environmental degradation and measures to be adopted for their management can be explained as follows:

Fertilizers contain trace amount of metals such as As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Sb, U and Zn. Heavy metals like cadmium and radioactive materials like uranium are harmful to humans so their application to the soil with fertilizer and their movement in the food chain is of concern.

Use of fertilizers

Nitrogenous fertilizers: To avoid the adverse effect of nitrogenous fertilizers (see 24.9) following measures should be adopted.

- Restriction should be imposed on the application of higher rates of nitrogen fertilizers.
- Minimize nitrate losses. Following practices can do this:
 - Use of nitrification inhibitors that retard oxidation of NH_4^+ to NO_3^-
 - Use of slow release or slowly soluble fertilizers to be added at appropriate rates.
 - Split application of nitrogenous fertilizers.

Plants tend to be more susceptible to NH_4^+ toxicity than to NO_3^- , but both can inhibit plant growth. Plants growing in the presence of high soil NO_3^- tend to accumulate NO_3^- in the plant tissues. Excess ingestion of nitrates may also increase the risk of cancer in human population as a whole. In animals nitrate poisoning includes mythemoglobinemia, dyspnea, salivation, weakness, abnormal or subnormal temperatures and cyanosis. Experimental work with dairy cattle indicates that minimum lethal dose (MLD-50) of nitrates was 4.5 kg per 50 kg of body weight (Hanway *et al.* 1963).

Phosphate fertilizers: The impact of cadmium borne phosphate fertilizers on its build up in the soil and utilization by crops has been a great concern. There is a need to monitor various long-term fertilizer experiments for build up of cadmium in treatments continuously receiving phosphate fertilizers.

Disposal of Waste Products

Increasing concern about environmental pollution has forced out great consideration on the disposal of urban and industrial wastes. The domestic and industrial sewage sludge is the major source of toxic elements. The major source for the disposal of these domestic and industrial wastes is the sewage system. It is necessary to ascertain about the level of inorganic and organic chemicals in the sludge prior to its application to the crops in the field. This will save the crop plants from toxicity hazard of these chemicals and will restrict the entry of these toxicants to the food channel.

Garbage

The municipal garbage after being composted is used to enhance crop production. The composted material contain about 0.5% N, 0.4% P and 0.2% K. City garbage contain many recyclable like plastics and metals, which are being regularly picked up by rag-pickers for the garbage recycling industries. If the harmful substances and other substances containing heavy metals and poisonous chemicals are separated from the decomposable organic matter, it could serve as a good material for composting.

Sewage Sludge and Effluent

Sewage sludge is the organic material produced from domestic and industrial wastewater and direct runoff from roads. Ground water pollution is one of the major environmental problems facing agriculture over the next 10 years. Soils receiving municipal waste water contained considerable higher quantities of total Cu, Zn, Cd and Pb than those receiving tube well irrigation did. Bayer *et al.* (1982) have reported that annual application of sewage sludge's containing toxic quantities of heavy metals have not only resulted in their building in soil but a

high concentration of cadmium and zinc in earthworms growing in such soils. (Table 24.7).

Beneficial Effects of Sewage Sludge

- The organic matter in sewage sludge helps to improve soil structure.
- The sludge, which contains organic material N, P, micronutrients and other substances, can be applied to improve plant growth. Sludge may be harmful due to
 - High concentration of soluble salts and heavy metals
 - Sewage sludge causes phytotoxicity where the sewage has been applied in large amounts over several years.

If serious contaminants are avoided, sludge could be used more extensively with greater safety.

Industrial Effluents

Utilization of natural resources like energy, land, water, air in industries causes environmental pollution and liberates toxicants, which in turn results into degradation of soil environment. This could be enlisted as follows:

- Fall out of heavy metals from shelters; markedly increase their level in the soil.
 - Application of water containing higher concentration of toxic elements like Cu, Zn, Pb, Cd and Ni resulted in the enrichment of top soil with these metal elements. Since the requirement of these elements to the plant is very less, they may become toxic and cause an adverse effect on the plant growth.
 - Entry of these elements into the food chain would cause health hazards to animals and human beings.
- iv) Most heavy metals become quite insoluble in soils of about pH 6.0 or basic. Cadmium being highly soluble than other heavy metals is frequently found contaminant. Nickel, copper, magnesium and zinc also occur as contaminants. pH 6.5 is desirable to reduce the solubility of heavy metals.
- v) Soil erosion: Soil erosion result, in following:
- i) The top eroded soil rich in plant nutrients is washed away.

Table 24.7. Effect of sewage sludge treatment on the content of heavy metal in soil and in earthworms growing in the soil

Metal	Concentration of metal (ppm dry weight)			
	Soil		Earthworms	
	Control	Sludge	Control	Sludge
Cd	0.1	2.7	4.8	57
Zn	56	132	228	452
Cu	12	39	13	31
Ni	14	19	14	14
Pb	22	31	17	20

Source: Bayer et al. (1982)

- ii) Filling of water reservoirs by sediment .It causes slide down, covers railway and homes.
- iii) It adversely affects activity of soil micro-organism destroying physical condition of soil.

Soil erosion causes pollution in the following ways

- i) Hindrance in human and animal activity.
- ii) Addition of salts carried by minerals contained in them.
- iii) Eroded materials are rich in nitrogen, phosphorus, and organic matter. These materials are carried through surface waters.

Following measures should be adopted to minimize the effect of erosion:

- i) Minimum tillage is an excellent management system to reduce soil erosion.
- ii) Maintaining crop residues on the soil surface, thus reducing the dispersion action of rainfall and decreasing the spread of water runoff.
- iii) Erosion control should be a part of the planning and legislative regulation.

Other pollutants

Soluble salts in soils, *insitu* or contributed through saline water irrigation management, radionuclides and acid rains cause soil pollution, and appropriate uses of river rain, ground and sea water and for the recycling of sewage water and industrial effluents.

MEASURES FOR EFFECTIVE CONTROL OF POLLUTION

Soil contamination by toxic elements can be prevented or reduced as discussed in section 24.6 of this chapter. In addition to the above, the following measures should be adopted for effective control of pollution.

Study of well waters of the adjoining area affected by pollutants

- i) Downward and lateral involvement of the effluent from industrial area may cause toxicity.
- ii) The effluent may be incorporated with under ground water through hydraulic flow along soil.
- iii) Well water of the area may get polluted with heavy metals. This makes water unsuitable for drinking. Irrigation with such water deteriorates soil.
- iv) The polluted water accumulates higher level of metallic cations and their enrichment may still be more in heavy textured soil.

Study of the Soil from Fields in the Vicinity of Industrial Areas

- Soil samples should be analyzed for EC, pH and physical properties like bulk density, hydraulic conductivity.
- Soil samples should be analyzed for elemental contents particularly heavy metals. (Cadmium, Zinc etc.)
- Soils should also be analyzed for cations Ca^{++} , Mg^{++} , Na^+ , K^+ , NH_4^+ and anions like Cl^- , F^- , $\text{SO}_4^{=}$, $\text{CO}_3^{=}$, HCO_3^- , NO_3^- (IV). The build up of Zn, Cu, Fe, Mn on different soil type and depth should be studied.

Crop Plant Analysis

- Elemental analysis in plant should be recorded. Plants accumulate high concentration of toxic materials of soil rich in their content.
- Toxic concentration of these materials may be recycled through man and animal being fed on such plant or animal products

Germination Study for Screening of Tolerant Genotypes

- Tolerant varieties of different crops should be screened through culture and laboratory studies.
- It has been found that effluent when diluted with normal water have no adverse effect on the germination of *kharif* and *rabi* crops.

Studies on Use of Amendments

- Suitable amendments should be incorporated in the soil. Use of amendment improves soil pH, physical properties like bulk density and hydraulic conductivity and increases yields. Following amendments are usually employed, (i) Phosphogypsum, (ii) Gypsum (iii) Pyrite (iv) Farmyard manure.
- Treatment of effluent with lime has decreased the levels of toxicants- heavy metals like zinc, copper, cadmium, lead, iron and anion like fluorine and phosphate.
- Incorporation of phosphogypsum in the soil has significantly decreased the accumulation of these metallic cations in the soil.
- Incorporation of pyrite in soil increases the level of available iron and manganese status of the soil. Totawat (1992) in his studies of soils affected by effluent being discharged from Zinc Smelter Debari, Udaipur found that incorporation of pyrites at 5 tonnes/ha resulted in a significantly higher grain and straw yields of maize and wheat Table 24.8.

Effluent dilutions for irrigation

- Dilution results in an increase in electrical conductivity and decrease in pH of the soil. The adverse effect of contaminated water could be minimized when mixed with normal water.
- Use of toxicated water (effluent) enhances the absorption of metallic actions far beyond the optimum requirement indicating their toxic build up in the plant. The accumulation of heavy metals in the roots is many folds more than they are content in the shoot.
- Normal yields can be obtained when such toxic water are diluted with normal water, however such polluted waters even after their dilution might not prevent the adverse effect of these toxic elements on plant metabolism.
- Such contaminated crop materials might enter in the food chain (the transfer of material through a number of organism for example a small fish eaten by a larger fish, the larger fish eaten by a bird and bird eaten by a hunter) and lead to accumulation of these cations into the body of animals and human beings dependent on such produce.

Organic Farming

Organic farming is production of crops through natural resources .It is farming

without the use of soluble fertilizers, or synthetic pesticides. For example, to meet the requirement for production of crops the following differences can be seen in organic and conventional farming (Table 24.9).

Agroforestry

Agroforestry refers to a form of land use by growing trees and shrubs in association with crops or pastures to maintain soil fertility and to control soil erosion. The beneficial effects of agroforestry can be listed as follows:

- Trees are a source of wood
- They protect soil against erosion through ground cover of litter and vegetation.
- They add to fixation of nitrogen with *Rhizobium* in some species.
- Trees reduce losses through leaching they retain nutrients in their tissues and return them to the soil surface.

Sustaining Soil Fertility

The practices adopted to sustain the fertility of soil depend on environment and economic circumstances. There is no one method of sustaining soil fertility that is universally applicable. For example, if erosion is a problem, conservation methods are a priority. Similarly, if soil acidity is the problem, it is necessary to prevent the soil from becoming acidic where fertilizers are costly inputs, it is important to recycle the nutrients.

Role of Micro Organisms to Reduce Pollution

Micro-organisms have the potential to recover pollutants or decompose it. Their efficiency can be improved by chemical treatments, selection of potential strains, genetic manipulation of strain etc to suit to the specific system. Biological agents can be used as indicators in restoration and monitoring of soil health. Microorganisms have the ability to degrade a variety of compounds for their survival and multiplication. These processes can be used for treating industrial wastes, residues of animal feed and food, removing of heavy metals.

- Microbial biomass has the ability to absorb metal ions. Micro-organisms function as biofilters.
- Metal recovering agent has been developed from dehydrated bacterial biomass. Metal recovery technology helps industry to clean up the environment.

Table 24.8. Effect of soil amendments on yield of maize and wheat grain in smelter polluted areas

Soil treatment	Maize tonnes	Wheat tonnes
No. of treatment	2.30	3.92
Phospho-gypsum	2.50	4.64
Gypsum	2.81	4.46
Pyrite	4.25	6.43
Farmyard manure	2.68	4.60

* Phosphogypsum, gypsum and Farmyard manure @ 10 tonnes ha⁻¹ and Pyrite @ 5 tonnes ha⁻¹

Source: Totawat and Chauhan (1992)

Table 24.9. Agricultural practices in organic and conventional farming.

Agricultural practices	Organic farming	Conventional farming
Requirement of nitrogen Requirement of phosphorus	Use of leguminous crops Ground rock phosphate and basic slag	Nitrogenous fertilizers Water soluble phosphate fertilizers
Requirement of potassium Control of insect pest and diseases, weeds	Crushed rock Agronomic practices that includes the use of rotations, selections of crop varieties resistant to disease and insect pests	Conventional fertilizers. Use of insecticides, herbicides, fungicides
To maintain the level of organic matter	Use of the animal manure, composted plant residues and green manure	Use of conventional fertilizers
Economic viability	It depends on the higher prices that customers will pay. The yields are lower than conventional farming	Economically more viable because of higher yields
Maintenance of soil fertility	It requires low external inputs to maintain soil fertility and produces food of high quality. It excludes the use of soluble fertilizers and pesticides	It requires higher inputs and produces food, which may not be of superior quality as compared those produced under organic farming systems. It includes the use of soluble fertilizers and pesticides

- Algae have been shown to concentrate heavy metal and have been applied to the development of water purification process for discharge streams.
- Micro-organisms play an active role in flocculation. Micro-organisms grow rapidly under aerobic conditions and oxidize, dissolve the suspended compounds in the wastewater.
- It is possible to adopt organisms to tolerate high concentration of metals.
- A few micro-organisms can degrade hydrocarbons in marine environments. For example *Chaetocerus calcitraras*, a diatom, indicate the potential use of organisms in reducing hydrocarbon-related pollutant.

References and Suggested Readings

- Alloway, B.J. (1990). *Soils and the Environment- an Introduction*. Cambridge University Press, UK.
- Anonymous (1993). *Proc. Regional FADNAP Seminar on Fertilization and the Environment*, Thailand.

- Bayer, W.N., Miller, G.W. and Cromatris, E.J. (1984). *Journal of Environment Quality* **13**: 247–51.
- Bayer, W.N., Chaney, R.L. and Mulhern, B.M. (1982). *Journal of Environment Quality* **11**: 381–385.
- Brown, A.W.A. (1978). *Ecology of Pesticides*. Interscience Publication. John Wiley & Sons. Tronto.
- Chopra and Singh (1976). *Wither Soil Research*. Transactions of the 12th International Congress of Soil Science, pp. 142, New Delhi, 1982.
- Fowler, E.B. (1961). *Radioactive Fallout*. Soils, Plants, Food, Man. Elsevier Science, Netherland.
- Gupta, H.C. L. (1998). *Insecticides, Toxioclogy and Uses*. Agrotech Publishing Academy. Udaipur – 313002 pp. 348
- Nemerom, R.L. (1976). *Industrial Water Pollution*. Addison Wesley.
- Raghunath, H.M. (1983). *Groundwater* Wiley Eastern Ltd., New Delhi.
- Singh Gurmel and Associates (1990). *Rainfed and irrigated agriculture for sustainable productivity*. Central Soil and Water Conservation Research and Training, Dehradun, India.
- Totawat, K.L. and Chouhan, B.S. (1992). *Indian Journal of Environmental Health* **34** : 28–32.
- Train, R.E. (1979). *Quality Criterion for Water*. Castle House Publication Ltd., London.

QUESTIONS

Q. 1. Fill in the blanks

- i) _____ are chemicals used to vise insects.
- ii) _____ are used to kill weeds without harming the crop.
- iii) _____ are the chemicals, which damage small mammals.
- iv) Fumigation is done for the control of _____.
- v) The process of _____ is often benefited by pesticide use.
- vi) Phosphate fertilizers contain on an average _____ cadmium /g of fertilizer.
- vii) Lead occurs as _____ in soil.
- viii) Much of the Zinc is strongly absorbed as _____ as on to iron and manganese oxides and clay alumino silicates.
- ix) Excess of _____ in drinking water causes dental and skeletal disorders.
- x) Arsenic in soils is present in anionic form as _____.
- xi) Insoluble forms of mercury are converted to a soluble inorganic form called _____.
- xii) Higher concentration of nitrates in drinking water contaminated with bacteria cause _____.
- xiii) Nitrate levels in drinking water above _____ are considered a human health hazard.
- xiv) The main concern of atmosphere pollution is related to _____.

- xv) Denitrification results in the biochemical reduction of nitrates or nitrites to gaseous form of nitrogen such as _____.
- xvi) Excess of potassium in grassland accompanied with higher applications of nitrogen may lead to _____ in cattle.
- xvii) The adverse effect of _____ water could be minimized when mixed with normal water.

Answers

(I) Insecticides (ii) Herbicides (iii) Rodenticides (iv) Nematocides (v) Ammonification (vi) 7mgm (vii) PbO_2 (viii) Zn(OH)^+ (ix) Fluorine (x) H_2AsO_4^- (xi) methylmercury (xii) blue baby disease (methaemoglobinemia) (xiii) 10 mg per litre (xiv) ozone shield (xv) molecular dinitrogen (N_2) or oxide of nitrogen (N_2O) (xvi) grass tetany (hypomagnesemia) (xvii) contaminated.

Q. 2. Choose the correct answer:

- i) Soil sterilizing agent ethylene dibromide diffuses through soil as a vapor/liquid phase.
- ii) In general, herbicides /fungicides are more mobile.
- iii) 2,4-D is rapidly degraded under aerobic/anaerobic conditions.
- iv) Most of the carbamates are toxic/not toxic to earthworms.
- v) Herbicide trifluralin is volatile/nonvolatile.
- vi) Much of the cadmium that enters the plant is retained in the roots/shoots.
- vii) Lead/copper is often deposited on leafy vegetables and is not easily removed by washing.
- viii) Cadmium/lead is highly soluble.
- ix) Use of toxicated water enhances/reduces the absorption of metallic cations
- x) The accumulation of heavy metals is more in the roots/shoots.
- xi) Most of the atmospheric ozone is found in the stratosphere/mesosphere.

Answer

(i) vapor (ii) herbicides (iii) aerobic (iv) volatile (v) toxic (vi) roots (vii) lead (viii) cadmium (ix) enhances (x) roots (xi) stratosphere.

Q. 3. Define

(i) Pollution (ii) Pollutant (iii) Radionuclides (iv) Nematocides (v) Photolysis (vi) Organic farming (vii) Agroforestry.

Q. 4. Differentiate between

(i) Radionuclides and Isotopes (ii) Biodegradable and Persistent pesticides (iii) Use of Chlorinated hydrocarbons and Organophosphates as insecticides (iv) Organic and Conventional farming.

Q. 5. Write short notes on

(i) Acid rain (ii) Heavy metals as a source of pollution (iii) Effect of pesticides on soil organisms (iv) Methylmercury (v) Eutrophication (vi) Ozone shield (vii) Beneficial effects of agroforestry.

Q. 6. Comment on the following statements

- i) An insecticide may become a pollutant.
- ii) Humus and montmorillonite are most effective for adsorbing pesticides.
- iii) Adsorbed pesticides are decomposed slowly.
- iv) Degradation of pesticides is faster at nearly neutral pH values.
- v) Degradation of atrazine is influenced by soil depth.
- vi) Use of DDT and BHC has been restricted.
- vii) Carbamates are more popular among environmentalists.
- viii) The population of bacteria increases after fumigation than before.
- ix) Use of pesticides can enhance biological nitrogen fixation.
- x) Addition of lead salts to soils produce only small increases in uptake.
- xi) At high concentration in soil zinc can be phytotoxic.
- xii) Soil contamination by toxic elements can be prevented by reducing soil application of materials containing toxic elements.
- xiii) The atmosphere acts as an insulator.
- xiv) Restriction is needed to be imposed on the application of higher rates of nitrogenous fertilizers.
- xv) The impact of cadmium borne phosphate fertilizers on its build up in the soil and utilization by crops has been a great concern.
- xvi) It is necessary to ascertain about the level of inorganic and organic chemicals in the sludge prior to its application to crops in field.
- xvii) pH 6.5 is desirable to reduce the solubility of heavy metals.
- xviii) Industrial effluents cause pollution.
- xix) It is important to study the well waters of the adjoining areas affected by pollutants particularly effluents.
- xx) Soil amendments control pollution.
- xxi) Use of contaminated crop materials might enter in the food chain.

Q. 7. Answer the following in brief

- i) Enlist problems that initiate pollution.
- ii) Enlist sources of soil pollution.
- iii) What does the term pesticides mean?
- iv) What characteristics should an ideal insecticide possess.
- v) What are the sources of inorganic pollutants.
- vi) Enlist inorganic chemical contaminants that cause pollution. Classify them according to their toxicity.
- vii) Enlist five gases that cause destruction of ozone layer.
- viii) Enlist factors influencing atmospheric pollution.
- ix) What are the beneficial effects of application of sewage sludge in agriculture?
- x) Why sludge's may be harmful to soils and plants?
- xi) What does sustaining soil fertility mean? Enlist some examples.

Q. 8. Answer the following in detail

- i) Explain the mechanism of metal tolerance by plants.
- ii) Explain the mechanism of pesticide adsorption.
- iii) Explain the reactions, which pesticides undergo in soil.
- iv) What is the role of cadmium and lead in pollution.
- v) Explain different ways of reducing the recycling of toxicants that may cause pollution.
- vi) Discuss the effect of nitrogenous fertilizers in causing pollution.
- vii) What are the effects of soil erosion on soil fertility? How soil erosion causes pollution, What are the measures that should be adopted to minimize the effect of erosion?
- viii) Explain measures to be adopted for effective control of pollution.

Q. 9. Give diagrammatic view of the following

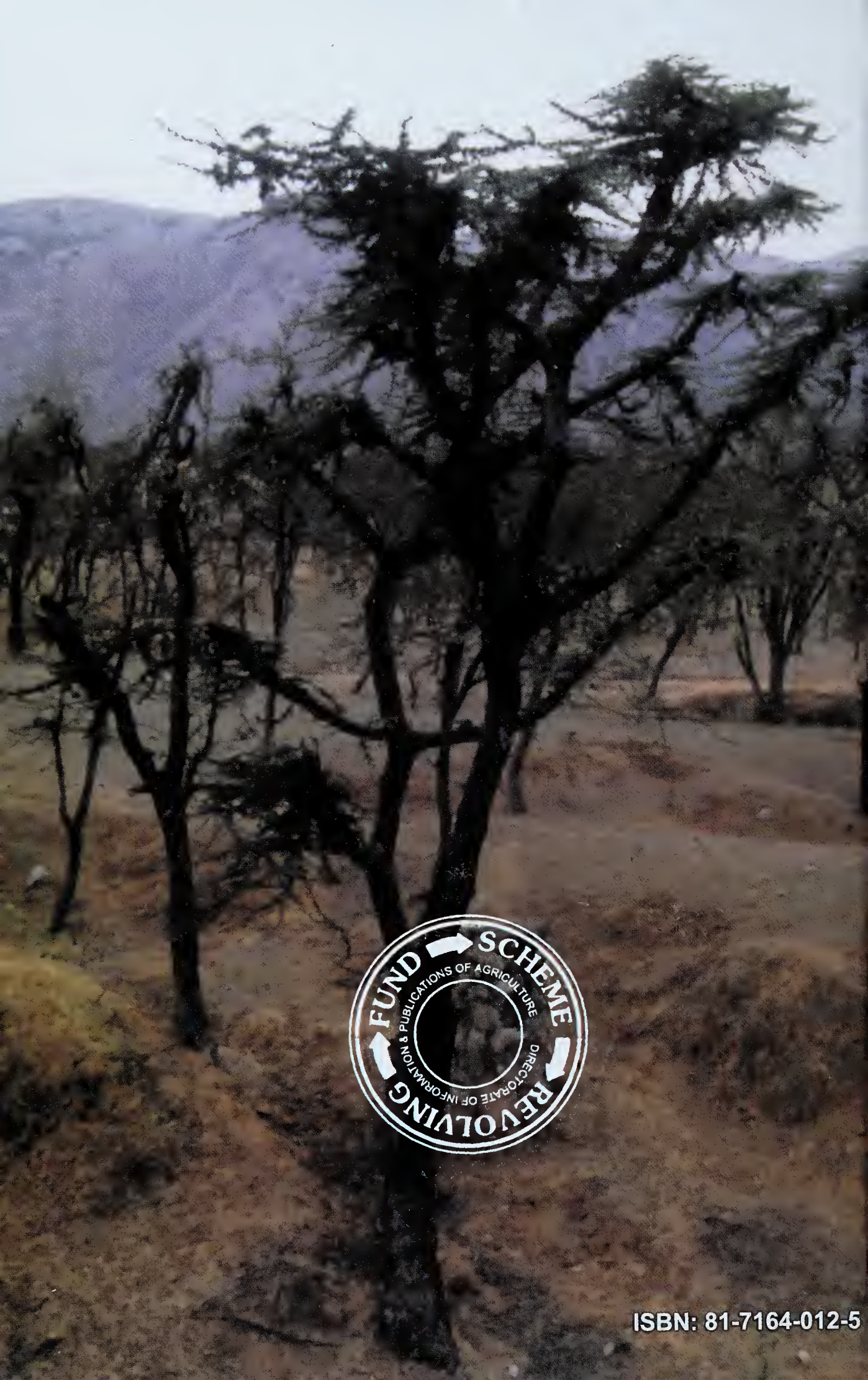
- i) Earth's atmosphere.



Index

- A soil, 8
- Accessory Minerals, 27
- Accumulation, 56
- Acid rain 270, 457
- Actinomycetes, 375
- Active Factors, 47
- Adjusted SAR 253
- Adsorbed Cations 128
- Adsorption 182, 461
- Aeration 446
- Agroforestry 479
- Agronomic practices 244
- Alfisols 77
- Algae 376
- Alkalization 65
- Allophanes 195
- Alluvial 43
- Alluvial Soils 85
- Alteration 196
- Aluminium 447
- Amensalism 384
- Amide Fertilisers 290
- Aminisation 284
- Ammoniacal Fertilisers 290
- Ammonification 284
- Ammonium chloride 291
- Ammonium sulphate nitrate 291
- Amphiboles 24
- Andisols 78
- Antibiotics 462
- Antidote 336
- Ants 379
- Argillaceous 31
- Aridisols 77
- Amaceous 31
- Arsenic 467
- Atmosphere 471
- Atmosphere 5, 151
- Autotrophs 374
- Available water 142
- Available Water 153
- Azonal soils 70
- Bacteria 373
- Bacterization 388
- Biofertilizers 428
- Biological Classification 142
- Biological weathering 42
- Biotite 193
- Black Soils 86
- Blocky 124
- Boron 467
- Brownian movement 185
- Buffering Action 226
- Buffering Curves 227
- Bulk Density 131
- BxP 359
- Calcification 64
- Calcite 17
- Calcium 447
- Calcium ammonium nitrate 291
- Calcium nitrate 291
- Capability classes 104
- Capillary water 142
- Carbamates 461
- Carbon cycle 404, 405
- Carbonaceous 32
- Carbonation 41
- Cataphoresis 185
- Catena 85
- Catenas 49
- Cation Exchange Capacity 207
- Cellulose 417
- Characteristics of soil 9
- Chelate 336
- Chemical classification 68
- Chemical Composition 19, 20
- Chemical Precipitates 31
- Chemical Precipitates 32
- Chemical Reactions 464
- Chemical Weathering 38
- Chemoautotrophs 374
- Chloride Concentration 254
- Chlorinated hydrocarbons 461
- Chlorine 351, 362
- Chroma 114
- Classification 103
- Clay 117
- Clay content 222
- Clay minerals 25
- Cleavage 18
- Climate 420, 127
- Climatic Conditions 350
- Climatogenic classification 69
- Coastal alluvium 85
- Coffey's system 69
- Cohesion 186, 18
- Colluvial 43
- Commensalism 384
- Competition 384
- Components of Soil 10
- Copper 468
- Crop harvest 285
- Cropping and Tillage 423
- Crotovinas 53
- Crystalline 188
- Crystallographic Characters 15
- Cultivation 159
- Cultivation 132
- Cultural Factors 382
- Cumulose 43
- CuxP 358
- Decomposition 56

- Deflocculation 130
- Degraded Alkali Soils 235
- Deltic alluvium 86
- Denitrification 285
- Desert Soils 88
- Detailed surveys 97
- Detrital inheritance 196
- Diagnostic Contacts 74
- Diagnostic Features 74
- Diagnostic Horizons 72
- Dialysis 185
- Dialysis or coagulation 185
- Diffusion 164
- Dimetric 17
- Drainage 238
- Earth's Crust 4
- Earth's Evolution 3
- Earthworm 53, 378
- Ecological Factors 382
- Economic classification 68
- Ectodynamorphic soils 47
- Ectomycorrhiza 388
- Edaphology 10
- Electro-osmosis 185
- Elicitors 387
- Eluviation 56, 63
- Endodynamorphic soils 47
- Entisols 75
- Environmental Factors 352
- Eolian 43
- Ericoid mycorrhiza 388
- Erosion losses 285
- Exchangeable ions 222
- Exchangeable sodium 238
- Exfoliation 37
- Expanding lattice 188
- Family 83
- Feldspars 22
- Ferrollysis 323
- Fertilizers 323
- FexP 358
- Field Capacity 145
- Final stage 50
- Flocculation 130
- Flooding 350
- Fluorine 467
- Frigid 75
- Fulvic acid 409
- Functions of soil 9
- Fungi 374, 375
- Fungicides 461
- Galena, halite 17
- Gapon equation 205
- Garbage 475
- Geological classification 68
- Glacial 43
- Gleization 65
- Gravimetric Method 148
- Gravitational potential 143
- Gravitational water 142
- Great Group 79
- Gypsum 17
- Halloysite 189
- Halogenic 69
- Hardness 18
- Hardpan Horizons 73
- Heavy Metals 459
- Hemicellulose 418
- Herbicides 462
- Heterotrophs 374
- Heterotrophs and Autotrophs 373
- Hexagonal 17
- Histosols 78
- Homogenization 57
- Hornblende 17
- Hue 114
- Humic acid 409
- Humic group 407
- Humification 62
- Humin 407, 408
- Humus 407
- Humus Formation 406
- Hydrogenic 69
- Hydrolysis 39
- Hydrometer Method 119
- Hydrosphere 5
- Hygroscopic Coefficient 146
- Hygroscopic water 142
- Hyperthermic 75
- Igneous rocks 28
- Illuviation 56, 63
- Inceptisols 76
- Increasing salinity 456
- Indicator method 224
- Industrial Effluents 476
- Infiltration 159
- Initial stage 50
- Inorganic colloids 183
- Inorganic fertilisers 290
- Inorganic Pollutants 458
- Inorganic sulphur 318
- Insecticides 461
- Intrazonal soils 70
- Iron 343, 361
- Iron imbalance 344
- Iron Sulfate 242
- Isoelectric Point 199
- Isometric 17
- Isomorphous substitution 198
- Juvenile stage 50
- Kononova's concept 408
- Lacustrine 43
- Lacustrine alluvium 86
- Laterite Soils 87
- Laterization 64
- Leaching 237, 463, 51



ISBN: 81-7164-012-5